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Characterization Well R-12 Completion Report

Los Alamos
NATIONAL LABORATORY

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Cover photo shows a modified Foremost Dual Rotary (DR-24) drill rig. The DR-24 is one of several drill-rig types being used for drilling, well installation, and well development in support of the Los Alamos National Laboratory Hydrogeologic Workplan. The Hydrogeologic Workplan is jointly funded by the Environmental Restoration Project and Defense Programs to characterize groundwater flow beneath the 43-square-mile area of the Laboratory and to assess the impact of Laboratory activities on groundwater quality. The centerpiece of the Hydrogeologic Workplan is the installation of up to 32 deep wells in the regional aquifer.

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David Broxton
Rick Warren
David Vaniman
Brent Newman
Andy Crowder
Mark Everett
Robert Gilkeson
Patrick Longmire
Jon Marin
William Stone
Steve McLin
David Rogers

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

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List of Acronyms

ASTM	American Society for Testing and materials
cps	count per second
CSF	combined scale factor
CVAA	cold vapor atomic absorption
DO	dissolved oxygen
DOC	dissolved organic carbon
DOE	Department of Energy
DR	dual rotation
EPA	US Environmental Protection Agency
ER	environmental restoration
FIMAD	Facility for Information Management, Analysis, and Display
ft MSL	feet above mean sea level
FSF	field support facility
GFAA	graphite furnace atomic absorption
GPS	global positioning system
HSA	hollow-stem auger
IC	ion chromatography
ICPES	inductively coupled plasma emission spectrometry
I.D.	inside diameter
IRMS	isotope radio mass spectrometry
LIKPA	laser-induced kinetic phosphorimetric analysis
LSC	liquid scintillation counting
MCL	maximum concentration level
MDA	minimum detectable activity
NAD	North American Datum
NGR	natural gamma radiation
NMED	New Mexico Environment Department
NOI	Notice of Intent
NTU	nephelometric turbidity unit
O.D.	outside diameter
PCB	polychlorinated biphenyl
PID	photoionization detector
PPE	personal protective equipment

PVC	polyvinyl chloride
QA	quality assurance
QXRD	quantitative x-ray diffraction
RC	reverse circulation
SVOC	semivolatile organic compound
SWL	static water level
TA	technical area
TD	total depth
TDS	total dissolved solid
TW	test well
UDR	underground drill rig
VOC	volatile organic compound
WCSF	waste characterization strategy form
XRF	x-ray fluorescence

Metric to English Conversions

Multiply SI (Metric) Unit	by	To Obtain US Customary Unit
kilometers (km)	0.622	miles (mi)
kilometers (km)	3281	feet (ft)
meters (m)	3.281	feet (ft)
meters (m)	39.37	inches (in.)
centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.394	inches (in.)
millimeters (mm)	0.0394	inches (in.)
micrometers or microns (µm)	0.0000394	inches (in.)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.5	acres
square meters (m^2)	10.764	square feet (ft^2)
cubic meters (m^3)	35.31	cubic feet (ft^3)
kilograms (kg)	2.2046	pounds (lb)
grams (g)	0.0353	ounces (oz)
grams per cubic centimeter (g/cm^3)	62.422	pounds per cubic foot (lb/ft^3)
milligrams per kilogram (mg/kg)	1	parts per million (ppm)
micrograms per gram (µg/g)	1	parts per million (ppm)
liters (L)	0.26	gallons (gal.)
milligrams per liter (mg/L)	1	parts per million (ppm)
degrees Celsius (°C)	9/5 + 32	degrees Fahrenheit (°F)

CHARACTERIZATION WELL R-12 REPORT

by

David Broxton, Rick Warren, David Vaniman, Brent Newman, Andy Crowder, Mark Everett, Robert Gilkeson, Patrick Longmire, Jon Marin, William Stone, Steve McLin, David Rogers

ABSTRACT

Characterization well R-12, located in Sandia Canyon near the eastern boundary of Los Alamos National Laboratory (the Laboratory), is the second of approximately 32 wells being installed in the regional aquifer as part of the Laboratory's “Hydrogeologic Workplan” (LANL 1998, 59599). R-12 was funded by the Laboratory’s Environmental Restoration (ER) Project and is primarily designed to provide water-quality and water-level data for potential intermediate-depth perched zones and for the regional aquifer. R-12 is downgradient of multiple contaminant source areas that potentially include release sites in the upper Sandia Canyon, Los Alamos Canyon, and Mortandad Canyon watersheds. R-12 is also sited to provide early warning for potential contaminants approaching water supply well PM-1 and to provide hydrologic and geologic data that contribute to the understanding of the vadose zone and regional aquifer in this part of the Laboratory.

R-12 was drilled to a total depth of 886 ft using air-rotary techniques, and a three-screen well was installed to provide access for sampling perched and regional zones of saturation. Drilling methods included downhole percussion hammers and dual-wall casing to drill open hole, a continuous-coring system to core open-hole, and Holte/Stratex casing-advance systems that operated on dual-wall casing and downhole percussion hammers. In descending order, geologic units penetrated in R-12 include alluvium, tephras and volcaniclastic sediments of the Cerro Toledo interval, the Otowi Member of the Bandelier Tuff, basaltic rocks of the Cerros del Rio volcanic field, old alluvium, the Puye Formation, and basaltic rocks of the Santa Fe Group.

A perched groundwater system was encountered in the lower part of the Cerros del Rio basalt and in underlying old alluvium. Water first appeared in the borehole at a depth of 443 ft, but rose to a depth of 424 ft. This may indicate confining conditions or that water entered the borehole too slowly to detect above 443 ft. Clay-rich lake beds at a depth of 519 ft act as the perching layer for this groundwater body. The saturated thickness of this perched zone is at least 76 ft, and it may be as much as 95 ft.

The regional water table was encountered at a depth of 805 ft in fractured basalt of the Santa Fe Group. The water is unconfined and occurs at about the same elevation as at R-9, located approximately .62 mi to the north. The elevation of the water table in R-12 is approximately 63.4 ft lower than the static water level in nearby supply well PM-1 under nonpumping conditions.

Groundwater samples were collected from the perched zone at depths of 443, 464, and 495 ft. These samples were chemically characterized with respect to major ions, trace elements, dissolved organic carbon, stable isotopes, tritium, and other radionuclides. Methods recommended by both the US Environmental Protection Agency and the Laboratory were followed for analysis of groundwater (filtered and nonfiltered) and core samples. Groundwater compositions are similar for the samples collected at depths of 443 and 495 ft, but the groundwater sampled at 464 ft has a distinctive chemistry.

Groundwater from the perched zone is dominantly a calcium-sodium-bicarbonate-chloride type, as represented by the samples collected at depths of 443 and 495 ft. There is also a sodium-calcium-chloride-sulfate-bicarbonate groundwater at a depth of 464 ft. Groundwater from the depths of 443 and 495 ft was

found to be characterized by 249 to 255 pCi/L tritium (analysis by low-level electrolytic enrichment), 31 to 33 parts per million (ppm) chloride, <0.02 to 0.26 ppm ammonium, 4.9 to 5.5 ppm nitrate, and 2.46 to 2.51 parts per billion (ppb) uranium. Groundwater from the depth of 464 ft was found to be characterized by 208 pCi/L tritium, 200 ppm chloride, 13.5 ppm ammonium, 0.21 ppm nitrate, and 2.04 ppb uranium.

Groundwater at the top of the regional saturated zone is a calcium-sodium-bicarbonate type, with a total dissolved solids content of 386 ppm. The major cation and anion chemistry of this water is similar to that of groundwater in supply wells PM-1 and PM-3. Measurable tritium activity in the regional saturated zone (47 pCi/L) suggests that a component of the groundwater is less than 50 years old.

1.0 INTRODUCTION

This report describes the drilling, well completion, and testing activities for characterization well R-12. R-12 is located in Sandia Canyon at the eastern Los Alamos National Laboratory (the Laboratory) boundary (Figure 1.0-1) west of state road NM 4 and north of East Jemez Road. This well was installed by the Environmental Restoration (ER) Project, and it is the second characterization well drilled to the regional aquifer as part of the "Hydrogeologic Workplan" (LANL 1998, 59599) in support of the Laboratory's "Groundwater Protection Management Program Plan" (LANL 1995, 50124).

R-12 is primarily designed to provide water-quality and water-level data for potential intermediate-depth perched zones and for the regional aquifer downgradient of contaminant release sites in the upper Sandia Canyon, Los Alamos Canyon, and Mortandad Canyon watersheds. R-12 is also sited to provide early warning of potential contaminants approaching supply well PM-1 (Figure 1.0-1) and to provide hydrologic and geologic data that contribute to the understanding of the vadose zone and regional aquifer in this part of the Laboratory. Data collected from R-12 will be used in conjunction with data from other planned characterization boreholes as well as from other data sources to evaluate and update the site-wide hydrologic conceptual model.

Preliminary interpretations are presented here for some of the data collected, but discussion of other data is deferred until they can be evaluated in the context of sitewide information collected from other ER Project and hydrogeologic work plan wells. A future report will provide an integrated human health and ecological risk assessment and will include groundwater data from other nearby ER Project wells.

R-12 is located 14.9 ft west of drill hole SCOI-3. SCOI-3 was completed to a depth of 132.5 ft before operations were suspended because of a lack of funds to complete the hole. SCOI-3 was specified in the "Task/Site Work Plan for Operable Unit 1049: Los Alamos Canyon and Pueblo Canyon" ("the work plan"; LANL 1995, 50290) as an intermediate-depth well, and its original intent was to allow for sampling of perched groundwater identified at a depth of 450 ft during installation of water supply well PM-1 in 1964 (Cooper et al. 1965, 8582). The purpose of SCOI-3 was reevaluated during development of the Laboratory's hydrogeologic work plan (LANL 1998, 59599), and a decision was made that a single well designed to characterize perched zones and the regional aquifer was needed at this location. This new well was named R-12, to be consistent with the nomenclature used to designate regional aquifer wells in the hydrogeologic work plan and the "Core Document for Canyons Investigations" ("the core document"; LANL 1997, 55622). Instead of deepening SCOI-3, R-12 was started as a new well so that larger casing sizes could be used to ensure that a well of adequate diameter could be installed in the regional aquifer.

Well R-12 was drilled in two phases. Phase I drilling occurred between March 10, 1998, and June 8, 1998, and the borehole was completed to a depth of 847 ft. A temporary well was installed to monitor water levels in the regional zone of saturation while water samples were analyzed for contaminants. Presence of significant contamination in the regional aquifer could have led to a decision to deepen the borehole in order to identify the vertical extent of contamination. After reviewing analytical results for groundwater samples collected from the borehole during drilling, a decision was made to complete R-12 as a three-screen well, with two screens located in the perched zone of saturation and one screen located at the top of the regional zone of saturation. Phase II drilling (to a total depth of 886 ft) and well installation occurred between October 25, 1999, and January 21, 2000.

Although R-12 is primarily a characterization well, its design also meets the requirements of a monitoring well as defined in Module VIII of the Laboratory's Hazardous Waste Facility Permit. Incorporation of this well into a Laboratory-wide groundwater monitoring program will be evaluated at a later date when the results of this characterization activity are integrated with other groundwater investigations in the hydrogeologic work plan (LANL 1998, 59599).

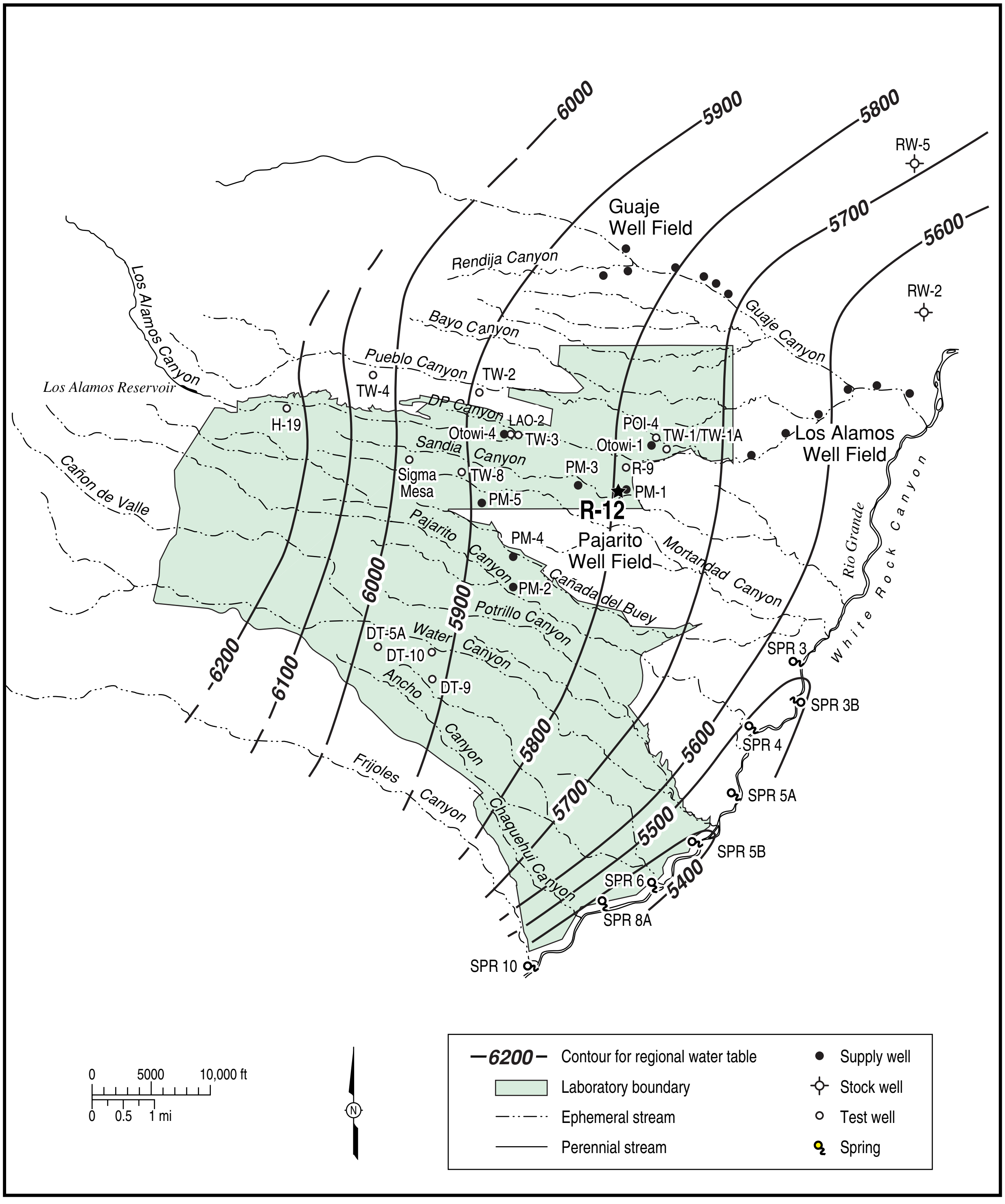


Figure 1.0-1. Locations of R-12, existing water supply wells and test wells, and generalized water-level contours for the regional water table

2.0 SUMMARY OF DRILLING ACTIVITIES

During the first phase of drilling, R-12 was halted at a depth of 847 ft, and a temporary characterization well was installed. During the second phase of drilling, the borehole was deepened to 886 ft and a permanent well with three screened intervals was installed.

2.1 Equipment

R-12 was drilled by Tonto/Dynatec Environmental Drilling Company (Dynatec). During the first phase of drilling, Dynatec used an Ingersoll-Rand T-4 drill rig with a T-5 rotating head. A Foremost dual rotation (DR)-24 drill rig was used during the second phase of drilling and for well installation. Final well development, hydrologic testing, and installation of the Westbay® Instruments, Inc., sampling system was completed using an underground drill rig (UDR) drill rig. Dynatec provided three-man drilling crews, crew vehicles, drilling hammers and bits, the Longyear 134-mm core system and dual-wall rod systems, a 1-ton flatbed truck, and a 5-ton boom truck for handling casing, drill pipe, and heavy support apparatus such as casing jacks.

The ER Project's field support facility (FSF) provided drill casings, drilling bits, a small front-end loader, the dust suppression system, field support trailers including logging and sampling, water containment tanks, drums for cuttings management, a Hermit data logger, depth-to-water meter, water sampling bailers, pressure transducers, and a diesel-powered electric generator. The Laboratory's Environmental Science and Waste Technology Division provided onsite water sample testing and filtering apparatus. The Geology and Geochemistry group (EES-1) of the Earth and Environmental Sciences Division provided core logging microscopes.

2.2 Schedule

The T-4 drill rig was mobilized to R-12 on March 10, 1998, and it was demobilized on June 8, 1998, after installation of the temporary casing. The Foremost DR-24 was mobilized to R-12 on October 25, 1999, and was demobilized on January 21, 2000. The UDR drill rig was mobilized on February 6, 2000, and was demobilized on March 18, 2000. Drilling operations required 96 drilling shifts, excluding time spent fishing for a dropped Bowen spear. Drilling shifts averaged 12 hr each, depending on production needs.

2.3 Production

Drilling techniques used in R-12 consisted of open-borehole drilling, air-rotary coring, air-rotary placement of a surface casing, and air-rotary under-reamer advance of five different casing strings. In addition, other drilling operations involved borehole/corehole/casing drill out, reaming, augering, milling, and cleaning. Changing drilling systems typically involved tripping-out one system, modifying the drilling head and/or circulation plumbing, and tripping-in another drilling system from the ground surface to the depth of operations. Production statistics are summarized in Table 2.3-1.

From the ground surface to 886 ft, the total footage drilled by the different drilling techniques and casing sizes was 1105.5 ft. The total footage drilled does not include the footage of one drill system or casing size tripped in or out of another drill system or casing size. The total trip-in footage was 19,551.5 ft, and the total trip-out footage was 19,796.5 ft.

Table 2.3-1
Performance Statistics for Characterization Well R-12

Drilling Types	Open Hole	Core	8-5/8-in. Casing[a]	10-3/4-in. Casing[b]	12-3/4-in. Casing[b]	14-in. Casing[c]	16-in. Casing	Casing Advance System (4-1/2-in. rods)[a]	Casing Advance System (7-in. rods)[b,c]	Total (ft)[d]
Total footage drilled (ft)	175	101	319	22.5	38	430	20	0	0	1105.5
Total footage rate (ft/hr)[e]	9.9	3.9	9.9	12.3	1.9	3.5	—[f]	—	—	—
Basalt footage (ft)[g]	155	9.5	48	0	38	319	0	0	0	569.5
Basalt rate (ft/hr)[e,g]	16.3	1.5	8.3		1.9	3.0	—	—	—	—
Puye clastics footage (ft)[h]	0	91.5	271	22.5	0	0	0	0	0	385
Puye clastics rate (ft/hr)[e,h]	—	7.3	10.2	12.3	—	—	—	—	—	—
Otowi Member footage (ft)[i]	0	0	0	0	0	111	20	—	—	131
Otowi Member rate (ft/hr)[e,i]	—	—	—	—	—	6.8	—	—	—	—
Trip-in footage (ft)	0	5885.5	300	480	448	20	0	6259	6159	19,551.5
Trip-in rate (ft/hr)[e]	—	356	138.5	71.1	45.9	—	—	286.7	302.5	—
Trip-out footage (ft)	0	5470	830	520.5	464	0	0	5222	7290	19,796.5
Trip-out rate (ft/hr)[e]	—	318	98.5	102.9	309.3	—	—	569.7	291.6	—
Pull back footage (ft)	0	0	126.5	0	0	0	0	0	0	126.5
Pull back rate (ft/hr)[e]	—	—	17.7	—	—	—	—	—	—	—
Mill shoe (number)[j]	—	—	—	—	—	2	—	—	—	—
Mill shoe (total hr)	—	—	—	—	—	15.7	—	—	—	—
Life-of-hole casing TD (ft)	—	—	—	—	0	449	20	—	—	—

Note: Performance statistics cover entire history of drilling.
[a] Stratex 6-5/8-in. and 8-5/8-in. casing-advance systems use 4-1/2-in. reverse circulation (RC) rods.
[b] Stratex 10-3/4-in. and 12-33/4-in. casing-advance systems use 7-in. RC rods.
[c] Holte 14-in casing-advance system used 7-in. RC rods.
[d] Total depth (TD) of borehole is 886 ft. Total cored footage (101 ft) is 11.4% of total borehole footage (886 ft).
[e] Rates are weighted averages over footages drilled or tripped, including breaks but excluding repairs and change out of tools.
[f] A dash in the table means “not applicable.”
[g] Basalt footage and rates include Cerros del Rio basalt and Santa Fe Group basalt.
[h] Puye Formation footage and rates include old alluvium.
[i] Otowi Member footage and rates include Cerro Toledo.
[j] Milling bits for 14-in. casing shoes are tripped in on 7-in. RC rods.

2.3.1 Open-Borehole Drilling

Open-borehole drilling was used to explore deeper sections of bedrock before coring or casing advancement. Dynatec drilled 175 ft of open borehole in basaltic rocks at an average rate of 16.3 ft per hr using an reverse circulation (RC) 44 4-7/8-in.-diameter percussion hammer, a 4 1/2-in.-diameter tricone roller bit, or an RC 44 10-in.-diameter percussion hammer. Open-borehole drilling in sedimentary strata was not attempted because of concerns about borehole stability.

2.3.2 Core Drilling

Core was collected in R-12 to provide undisturbed samples for geological, contaminant, and hydrological characterization. In addition, core was used to identify perching layers beneath perched groundwater and to provide information for placing casing seals. Core was not collected from the land surface to a depth of 132.5 ft because this interval was continuously cored during drilling of SCOI-3. The SCOI-3 core is archived at the FSF. In R-12, Tonto cored a total of 101 ft, or 11.4% of the 886-ft depth.

In R-12, average core recovery was 72.6% from all cored intervals. Of the 101 ft cored, 9.5 ft of core were produced from basaltic rocks at an average rate of 1.5 ft per hr and average recovery of 72%; 101 ft of core were produced from sedimentary rocks at an average rate of 7.3 ft per hr and average recovery of 82%.

Coring operations in R-12 were performed with a Longyear 134-mm coring system. A 101-mm coring system was used during drilling of R-9 but was found to lack the strength and stability for coring through large-diameter casing sizes. Unfortunately, the new 134-mm system used in R-12 provided poor performance because of repeated failure in the latching system. The poor performance of this coring system reduced the amount of core collected in R-12. The coring system was returned to the manufacturer for modifications to the latching system, and performance of this system should improve in future boreholes.

2.3.3 Casing Advancement

After the 16-in.-diameter surface casing was installed, multiple telescoped casing strings were installed to advance the borehole and to prevent perched water from communicating downhole as the borehole advanced. As a casing string was used to seal off a perched water zone (e.g., 14-in.-diameter casing), the casing shoe was milled downhole, allowing the next-smaller casing size to advance past the shoe and continue borehole production. Table 2.3-1 lists the casings and casing-advance systems used.

2.3.4 Other Drilling Activities

Other drilling activities included milling the casing shoes and reaming the borehole. These activities also included operations to clean clay cake from drill bits, casing, and air-circulation equipment during drilling of clay-rich rock units.

3.0 R-12 STRATIGRAPHY/LITHOLOGY

The principal geologic units encountered in R-12, in descending order, consist of alluvium, tephras and volcaniclastic sediments of the Cerro Toledo interval, the Otowi Member of the Bandelier Tuff, a late Pliocene soil, basalts of the Cerros del Rio volcanic field, old alluvium, sediments of the Puye Formation, and basaltic rocks of the Santa Fe Group. A detailed description of these units and of subunits within them is provided in the lithologic log of Appendix A. Samples of representative lithologies were collected for further analysis; a listing and description of each of these samples is given in the geologic sample descriptions of Appendix B. All of the samples listed in Appendix B include descriptions obtained either by binocular microscope or by petrographic microscope using thin sections. A subset of these samples was analyzed by quantitative x-ray diffraction (QXRD); results of these analyses are listed in Table 3.0-1 and are discussed throughout this section. Twenty-three representative samples were analyzed by x-ray fluorescence (XRF) for major and trace elements with results listed in Table 3.0-2. The XRF data are referred to in relevant subsections of the text below.

Table 3.0-1
Quantitative X-Ray Diffraction Analyses of Samples from Drill Hole R-12

Sample	Smectite	Kaolinite	Mica	Zeolite	Quartz	Cristobalite	Tridymite	Feldspar	Glass	Hematite	Amphibole	Calcite	Total
R12-15D Cerro Toledo; pumiceous (cuttings)	1(1)	tr	tr	tr	27(2)	4(1)	1(1)	39(5)	28(5)	tr	tr		100(6)
R12-85D Otowi vitric ash (cuttings)	2(1)		tr	tr	20(2)	2(1)	1(1)	28(4)	47(4)	tr	tr		100(5)
R12-105D Otowi pumice, ash-free (cuttings)	1(1)				9(1)	1(1)		16(2)	73(2)	tr			100(3)
R12-120D Guaje vitric bedded tuff (cuttings)			tr		21(2)			18(3)	61(3)				100(4)
R12-131.5D sandy tuff with basalt (cuttings)	13(4)	1(1)	1(1)	1(1)	24(2)	1(1)	tr	25(4)	34(6)	tr	tr		100(6)
R12-520.5 lacustrine unit, old alluvium (core)	54(16)	8(2)	1(1)	1(1)	21(2)			8(1)		tr	tr	3(1)	96(16)
R12-555D Puye conglomerate (cuttings)	1(1)		tr		3(1)	11(1)	8(1)	56(8)	20(8)	1(1)			100(8)
R12-565D Puye sand (cuttings)	1(1)	tr	1(1)		4(1)	11(1)	5(1)	52(7)	24(7)	1(1)	1(1)		100(7)
R12-605D Puye gravel (cuttings)			1(1)		8(1)	10(1)	6(1)	55(8)	19(8)	1(1)	tr		100(8)
R12-630D Puye gravel, rounded (cuttings)	6(2)	tr	1(1)	1(1)	14(1)	7(2)	4(1)	47(7)	18(7)	1(1)	1(1)		100(8)
R12-655D Puye gravel (cuttings)			1(1)		9(1)	9(3)	8(1)	55(8)	17(8)	1(1)	tr		100(9)
R12-710D Puye sandstone (cuttings)	15(5)		1(1)		3(1)	15(1)	1(1)	60(8)		2(1)	1(1)		98(10)
R12-720 Puye pumiceous sand (core)	93(28)				2(1)			2(1)			tr		97(28)
R12-726.4 Tephra layer within Puye (core)	96(29)	tr		1(1)	1(1)			2(1)		1(1)	2(1)		103(29)
R12-730.6 Puye sandstone (core)	39(12)	1(1)	1(1)	1(1)	3(1)	6(2)		50(7)		1(1)	1(1)		103(14)
R12-751.1 Puye graded pumiceous sand (core)	71(21)	tr	tr	1(1)	9(1)			10(1)		1(1)	1(1)	tr	93(21)
R12-779.5 Puye pumiceous sand (core)	54(16)	tr	tr	tr	7(1)	2(1)		33(5)		1(1)	1(1)	tr	98(17)

Notes: 1. All entries are in weight percent with approximate 2σ uncertainties in parentheses.
2. tr = trace (detected at <0.5%).

3.1 Alluvium (0- to 12.5-ft depth)

The alluvium at R-12 is pumiceous and contains abundant 1- to 2-mm crystals of quartz and chatoyant sanidine derived from the Bandelier Tuff. Alluvium is distinguished from underlying Cerro Toledo interval by its marked paucity of fine-grained matrix.

Table 3.0-2
Chemical Analyses of Representative Samples from Drill Hole R-12

Sample	R12-15D	R12-85D	R12-105D	R12-120D	R12-131.5D	R12-138.5D	R12-228D	R12-270D	R12-380D	R12-442D	R12-520.5	R12-555D
Stratigraphic Unit	Cerro Toledo	Otowi	Otowi	Guaje	soil	Cerros del Rio	Cerros del Rio	Cerros del Rio	Cerros del Rio	Cerros del Rio	old alluvium	upper Puye
Sample type	cuttings	cuttings	cuttings	cuttings	cuttings	cuttings	cuttings	cuttings	cuttings	cuttings	core	cuttings
SiO_2 %	76.70	75.39	75.24	77.06	68.92	52.05	51.28	50.25	48.93	47.72	60.04	68.39
TiO_2 %	0.22	0.21	0.14	0.11	0.51	1.52	1.42	1.46	1.82	1.85	0.67	0.48
Al_2O_3 %	12.08	12.64	12.97	11.86	14.26	16.31	16.08	16.68	16.12	16.08	16.32	14.87
Fe_2O_3 %	2.03	1.95	1.69	1.58	3.80	11.18	11.62	11.67	11.08	11.19	5.20	3.77
MnO %	0.07	0.06	0.07	0.07	0.08	0.16	0.16	0.17	0.17	0.17	0.03	0.06
MgO %	0.32	0.36	0.21	0.18	1.36	5.87	7.31	6.97	7.92	8.12	2.39	1.80
CaO %	0.54	0.85	0.55	0.47	1.41	9.01	8.97	9.16	9.09	9.17	3.14	3.12
Na_2O %	3.26	3.67	3.78	3.63	2.19	3.38	3.20	3.21	3.47	3.06	0.30	3.59
K_2O %	3.76	3.84	4.13	3.65	2.70	0.96	0.91	0.91	1.54	1.46	2.63	3.26
P_2O_5 %	0.02	0.05	0.03	0.02	0.08	0.31	0.30	0.32	0.67	0.70	0.16	0.24
LOI %	2.13	1.80	2.16	2.16	5.03	-0.07	-0.30	-0.14	-0.37	0.59	9.66	1.13
Total %	101.22	100.93	101.06	100.90	100.51	100.92	101.45	100.99	101.14	100.48	100.71	100.93
V ppm	21	23	0	13	50	160	183	171	195	206	108	50
Cr ppm	0	9	0	0	34	141	248	228	233	222	59	49
Ni ppm	0	0	0	0	0	59	96	86	158	144	25	25
Zn ppm	71	70	77	88	86	102	88	72	97	87	102	52
Rb ppm	139	134	184	235	168	10	21	16	26	18	113	75
Sr ppm	73	112	56	42	175	421	427	427	884	1085	148	411
Y ppm	61	39	54	66	49	31	39	22	29	43	34	14
Zr ppm	217	169	201	187	341	149	138	140	223	220	175	163
Nb ppm	48	76	84	127	85	17	22	20	33	26	22	0
Ba ppm	206	322	112	88	431	377	394	389	816	983	468	1101

Table 3.0-2 (continued)

Sample	R12-565D	R12-605D	R12-630D	R12-655D	R12-710D	R12-720	R12-726.4	R12-730.6	R12-751.1	R12-779.5	R12-810D
Stratigraphic Unit	upper Puye	upper Puye	upper Puye	upper Puye	mid Puye	lower Puye	lower Puye	lower Puye	lower Puye	lower Puye	Miocene basalt
Sample type	cuttings	cuttings	cuttings	cuttings	cuttings	core	core	core	core	core	cuttings
SiO_2 %	66.98	69.60	68.67	70.60	64.74	58.60	58.79	59.86	60.17	60.52	49.38
TiO_2 %	0.49	0.41	0.48	0.38	0.65	0.71	0.74	0.75	0.77	0.84	1.73
Al_2O_3 %	15.79	14.72	14.56	14.58	16.86	19.19	19.17	18.23	18.02	17.60	16.64
Fe_2O_3 %	3.86	3.22	3.37	2.94	4.45	5.78	4.82	5.23	5.04	5.31	10.98
MnO %	0.06	0.05	0.05	0.07	0.06	0.10	0.07	0.08	0.09	0.09	0.15
MgO %	1.73	1.36	1.46	1.30	1.55	4.27	4.85	2.77	3.99	3.36	5.70
CaO %	3.27	2.67	2.35	2.60	3.66	3.38	3.56	4.26	2.98	3.77	10.64
Na_2O %	3.73	3.60	3.06	3.54	3.79	0.25	0.26	3.04	0.70	2.28	3.35
K_2O %	3.09	3.46	3.22	3.50	2.74	0.46	0.28	1.65	1.40	1.26	0.89
P_2O_5 %	0.17	0.14	0.13	0.11	0.22	0.16	0.14	0.24	0.19	0.21	0.38
LOI %	1.37	1.01	2.63	1.05	1.77	7.41	7.62	4.08	7.27	4.74	0.97
Total %	100.77	100.45	100.18	100.87	100.78	100.46	100.42	100.47	100.81	100.19	101.06
V ppm	53	37	42	32	59	79	58	79	58	77	227
Cr ppm	45	44	45	37	37	95	30	42	23	41	240
Ni ppm	16	25	21	28	25	55	32	27	17	22	85
Zn ppm	55	39	51	39	62	51	75	60	51	58	78
Rb ppm	63	84	89	90	42	13	0	31	38	31	10
Sr ppm	464	359	333	333	576	251	254	638	244	464	611
Y ppm	15	26	22	38	22	9	8	25	0	18	30
Zr ppm	165	157	211	146	216	181	187	244	194	283	153
Nb ppm	21	30	21	21	29	20	22	22	15	22	21
Ba ppm	1041	909	924	843	1252	367	306	1123	829	838	413

3.2 Volcaniclastic Sediments of the Cerro Toledo Interval (12.5- to 31.3-ft depth)

Reworked tuff of the Cerro Toledo interval at R-12 is massive, brown, and vitric, except within a basal 2-ft zone that contains abundant lithics of dark, intermediate-composition lava, and a 1-ft-thick pumice-rich zone which overlies this lithic-rich zone. A sample from 15-ft depth, within the massive reworked material, consists of vitric pumice with felsic phenocrysts. Included within this sample are rare lithic fragments of devitrified nonwelded tuff. QXRD analysis of this sample (Table 3.0-1) indicates very little clay alteration (~1 wt % smectite) with high abundance of crystals (71 wt %) relative to glass (28 wt %).

3.3 Otowi Member of Bandelier Tuff (ash flow from 31.3- to 112-ft depth; Guaje Pumice Bed from 112- to 131-ft depth)

The main body of the Otowi Member is a massive, vitric, nonwelded ash-flow tuff at 31.3- to 102-ft depth, underlain by a vitric ash-flow tuff that is pumice-rich and depleted in fine ash from 102 to 112 ft. An exceptionally pumice-rich tuff occurs at 104.9- to 105-ft depth. The Guaje Pumice Bed extends from 112 to 131 ft and includes bedded pumice fall deposits depleted in fine ash from 112- to 117-ft depth. Near its base, the Guaje Pumice Bed is partly vitric and partly clay-altered.

QXRD analysis typical of the central part of the ash-flow deposits at 85-ft depth (Table 3.0-1) shows a lithology that consist of 47 wt % glass and 51 wt % felsic minerals (principally feldspar and quartz). The pumice-rich tuff at 105-ft depth is relatively crystal poor (73 wt % glass and 26 wt % crystals). These contrasts within the Otowi ash flow indicate that a much higher concentration of crystals occurs within the fine matrix than in the pumice.

Although the Guaje Pumice Bed is clay-altered at its base, the QXRD analysis of a sample 11 ft above the base of the unit has no clay and 61 wt % unaltered glass (sample R12-120D, Table 3.0-1). Tridymite and cristobalite are absent in this sample; quartz is the only silica polymorph present, and probably occurs almost entirely as a phenocryst phase.

3.4 Late Pliocene Soil (131- to 132.5-ft depth)

A thin late Pliocene soil overlies basaltic rocks of the Cerros del Rio volcanic field in R-12. This soil is probably correlative with soil exposed in the road cut along state road NM 502, near the junction of Los Alamos and Pueblo Canyons, 1.8 km northeast of R-12. The soil in R-12 consists of fine, oxidized sand that contains fragments derived from the underlying basalt. The soil is distinguished from the clay that is associated with flow boundaries within the sequence of underlying basaltic rocks by its coarser grain size.

This soil includes a discolored fine sand that is largely crystalline and a coarser sand that consists of basalt and pumice fragments. QXRD analysis of this soil (Table 3.0-1, sample R12-131.5D) shows that the vitric component associated with the pumice is significant (34 wt %), despite alteration of the deposit to 14 wt % clay and a small amount of zeolite. The low clay abundance, preservation of glass, and absence of calcite indicate that this soil is very immature.

3.5 Late Pliocene Basaltic Rocks of the Cerros del Rio Volcanic Field (132.5- to 491.6-ft depth)

Late Pliocene basaltic rocks of the Cerros del Rio volcanic field consist of vesicular to massive basalt flows, thin zones of basaltic breccia, paleosols, and a thin basal layer of basaltic tephra. Four flow units are distinguished by their textural characteristics or by the recognition of vesicular zones that overlie or underlie massive flow interiors. These flow units are tentatively correlated with four flow units in R-9 (Broxton et al. 2000, 66599) and consist of, in descending order, an upper tholeiitic flow, a lower tholeiitic flow, an upper alkalic flow, and a lower alkalic flow (Figure 3.5-1). The age of the Cerros del Rio basalts in R-12 has not been determined. However, in R-9 the upper tholeiitic flow unit has an age of 2.15 Ma, and the lower alkalic flow has an age of 2.45 Ma (see Table 3.2-1 in Broxton et al. 2000, 66599).

In R-12, flow-unit boundaries are characterized by the presence of abundant clay. These clays, which give rise to sharply higher moisture contents (see Section 5.4 of this document), occupy vesicles and fractures at the tops and bottoms of basalt units. The upper alkalic flow and the lower alkalic flow in R-12 are separated by a paleosol that occurs between the depths of 411 and 419.2 ft. In contrast, flow unit boundaries in R-9 were generally difficult to recognize because clay or other secondary minerals were not associated with some of the contacts.

Chemical analyses of five samples of the late Pliocene basalt are listed in Table 3.0-2. The chemical trends from lower to upper flow units (Figure 3.5-2), include increasing silica content and increasing indices of evolution [i.e., decrease in the Mg#, which represents the cation ratio Mg/(Mg+Fe)]. Both these parameters reflect fractionation resulting in higher SiO_2 and lower Mg, constituents that are of respectively low or high concentration in the olivine that is removed through crystal fractionation. Other elements such as Sr reflect the difference between alkali and tholeiitic character, and elements such as Al increase slightly with olivine fractionation but also reflect other aspects of basalt origin, such as crustal contributions to magma sources.

3.5.1 Upper Tholeiite (132.5- to 260.5-ft depth)

Two samples of the upper tholeiite, from 138.5- and 228-ft depth, are massive olivine-porphyritic lavas with rare glomerocrysts of olivine and plagioclase. Phenocryst sizes are 0.2–1.2 mm for olivine and 0.5–1.5 mm for plagioclase. Optical properties of the plagioclase phenocrysts and of groundmass feldspar indicate compositions that are typically about anorthite-45 to anorthite-55.

The upper tholeiite in R-12 is the thickest of the recognized Pliocene flows in this drill hole and is represented by two chemical analyses (Table 3.0-2, Figure 3.5-2). Silica variation for the two samples from this flow fall along a consistent trend that decreases with depth across all the Pliocene flows (Figure 3.5-2). The corresponding decrease in Mg# from bottom to top is not as systematic but follows a general trend that is in accord with predominant olivine fractionation. This consistent variation is the same as that seen for these units in drill hole R-9 and supports the same conclusion of genetic relationship of all flows in the Pliocene sequence through fractionation.

High K_2O/P_2O_5 values (3.0 to 3.1) in the upper tholeiite correspond closely with the high end of the trend of SiO_2 contents in the sequence of Pliocene basalts (Figure 3.5-2). Because K and P are both concentrated and seldom fractionated from each other during fractional crystallization in basalts, and K_2O/P_2O_5 values are generally higher in crustal rocks than in mafic lavas, the relations between SiO_2 and K_2O/P_2O_5 shown in Figure 3.5-2 suggest crustal contamination along with fractionation in the transition from less-evolved alkaline basalts to more evolved tholeiites. Isotopic studies of the Cerros del Rio volcanic field support this conclusion.

3.5.2 Lower Tholeiite (260.5- to 342.3-ft depth)

A sample of the lower tholeiite, from 270-ft depth, is a vesicular basalt with small (0.2–0.8 mm) olivine phenocrysts. Plagioclase phenocrysts occur but are very rare. Optical properties of the plagioclase phenocrysts and of groundmass feldspar indicate similar average compositions of about anorthite-60. The few plagioclase phenocrysts occur both singly and in clots and have sieved cores.

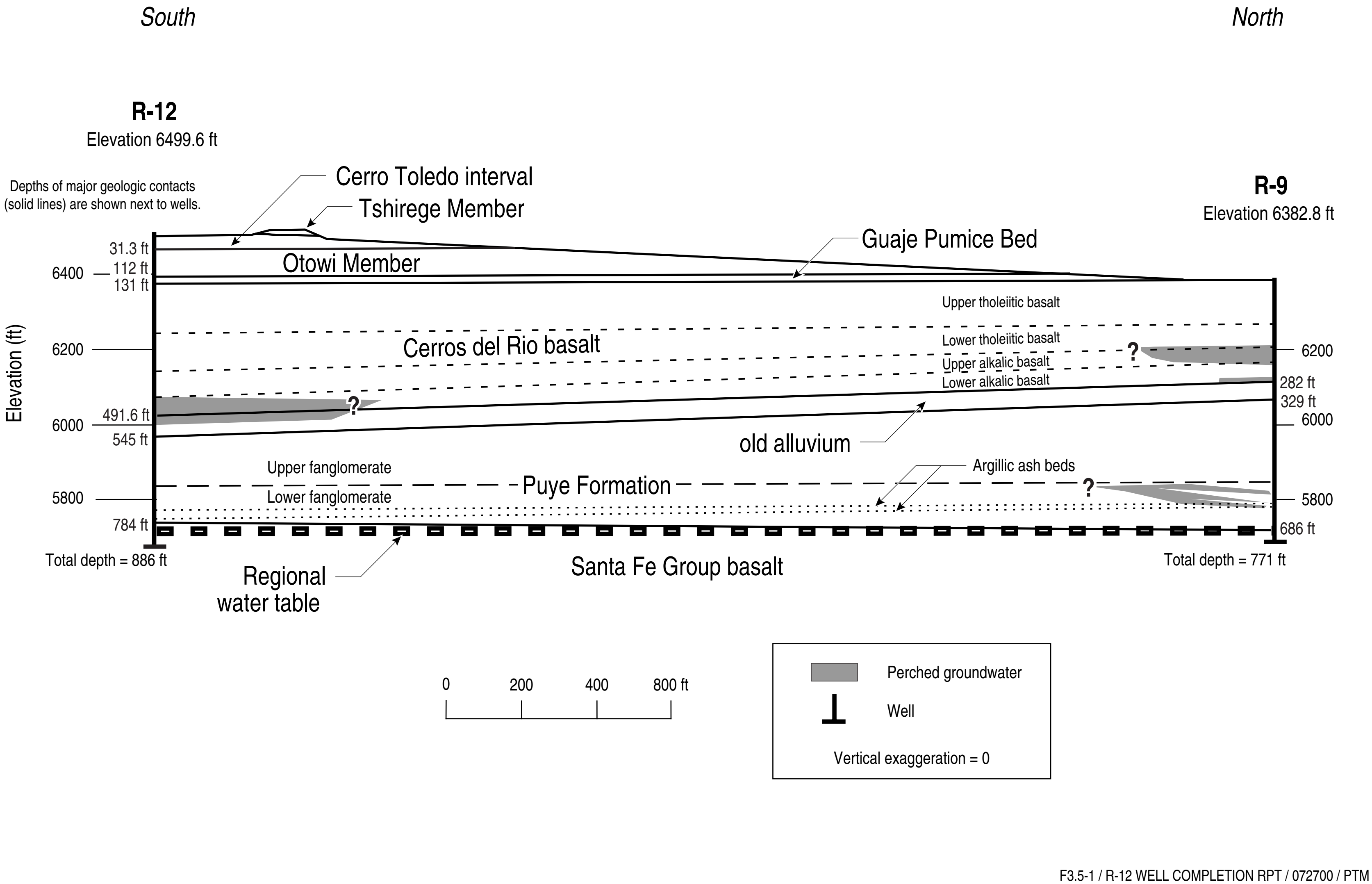


Figure 3.5-1. North-south cross-section showing correlation of geologic units and occurrences of groundwater in R-9 and R-12

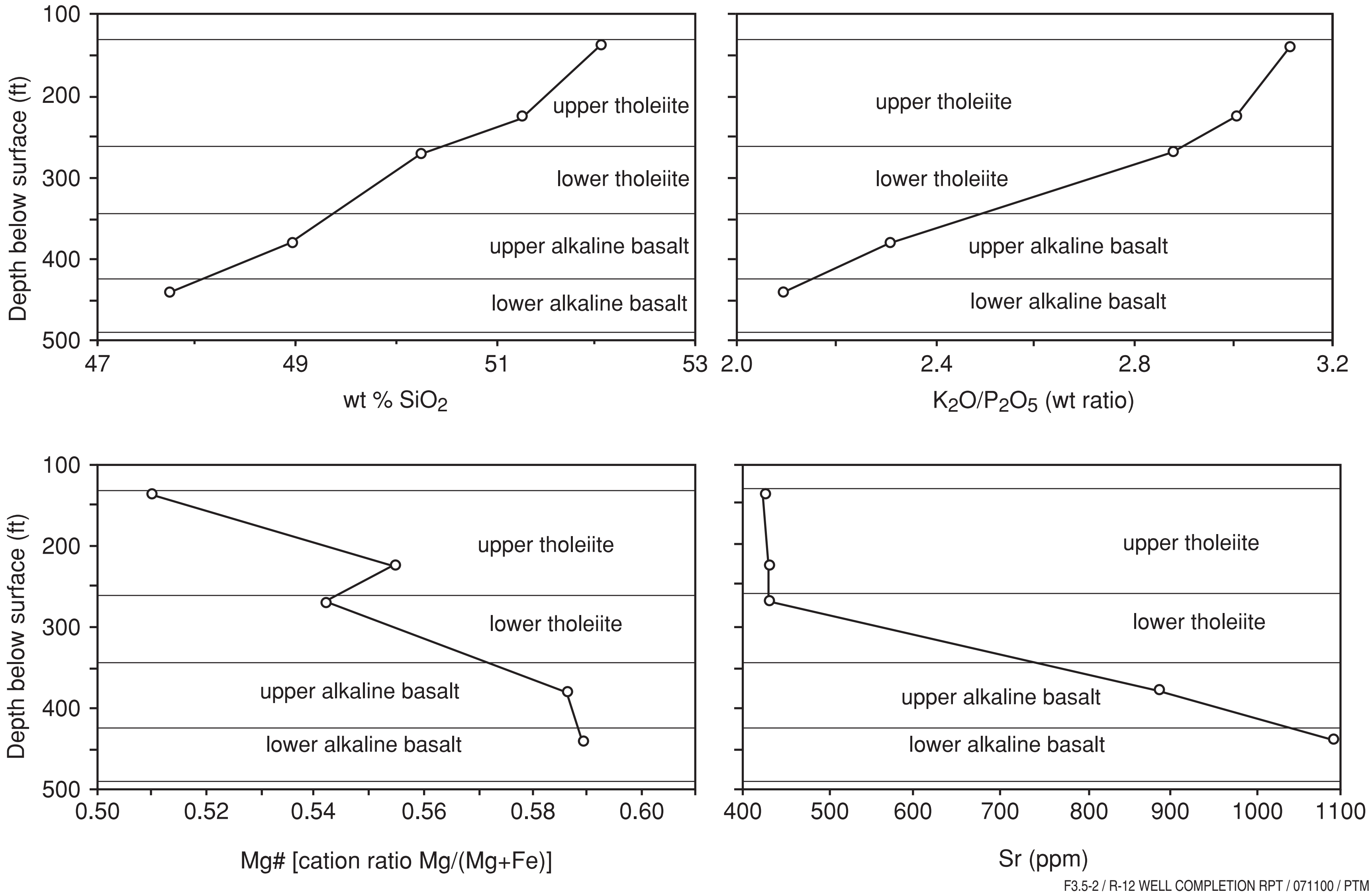


Figure 3.5-2. Variations in SiO_2, K_2O/P_2O_5, Sr, and Mg# [cation ratio of Mg/(Mg+Fe)] with stratigraphic depth in the sequence of Pliocene basalts sampled at R-12. Data for these plots are in Table 3.0-2.

The lower tholeiite falls along compositional trends contiguous with or overlapping the trends projected from the upper tholeiite with depth (Figure 3.5-2). Continuity in composition occurs despite evidence of a flow contact and hiatus in eruption history between the two tholeiites at 260.5-ft depth. Notable is the consistent and low Sr content of the tholeiite samples, in contrast to the much higher Sr contents of the earlier alkaline basalts (Figure 3.5-2).

3.5.3 Upper Alkalic Basalt (342.3- to 411-ft depth) and Paleosol or Lacustrine Interval (411- to 419.2-ft depth)

A sample of the upper alkalic basalt, from 380-ft depth, is a moderately vesicular olivine-porphyritic basalt with rare phenocrysts of plagioclase and orthopyroxene. The olivine phenocrysts (0.2–1.0 mm) are subhedral and commonly contain crystallized melt inclusions. Optical properties of the plagioclase phenocrysts indicate a common composition of anorthite-35.

Both the upper and lower alkaline basalts at R-12 have high Mg#s (>0.58) and are thus less evolved than the overlying tholeiites (Figure 3.5-2). In measures of fractionation such as Mg# and SiO_2 content, the alkaline basalt compositions suggest a continuity with the overlying tholeiites, but there is a large gap in Sr content between the alkaline and tholeiitic series that may be attributed either to plagioclase fractionation (unlikely, in view of the scarcity of plagioclase phenocrysts), or to differences in Sr components of source regions or crustal contaminants. Isotopic studies would be necessary to resolve these questions.

A paleosol or lacustrine interval at 411- to 419.2-ft depth provided poor core recovery, but the samples returned contained abundant clay. Extensive clay alteration was observed in the upper few feet of the lower alkalic basalt.

3.5.4 Lower Alkalic Basalt (419.2- to 488.9-ft depth)

A sample of the lower alkalic basalt, from 442-ft depth, is olivine porphyritic with euhedral to subhedral olivine phenocrysts of 0.2 to 1.2 mm. Alteration of olivine to iddingsite assemblages is more extensive in these cuttings than in the overlying basalts, but is nevertheless only partial. Groundmass textures in thin section range from intergranular to a texture that is almost trachytic (strong parallel orientation of groundmass feldspar laths).

This is the most primitive of the Pliocene basalts in drill hole R-12. However, relative to evolution parameters of continental basalt types, even this lava can not be considered primary. Alkaline lavas transported from mantle sources with little fractionation or crustal assimilation typically retain Mg#s of ~0.7, considerably higher than any of the Pliocene basalts of the Cerros del Rio volcanic field. The extensive compositional ranges and large eruptive volumes within this volcanic field suggest that large batches of basaltic magma accumulated in interim magma chambers and had considerable opportunity for fractionation and wall-rock assimilation prior to eruption. These processes bear on the ultimate volumes of basalt erupted and the lateral continuity of these basalt units; these aspects of basalt evolution are important in defining basalt distributions in the Laboratory sitewide three-dimensional geologic model.

3.5.5 Alkalic Basalt Tephra (488.9- to 491.6-ft depth)

Basaltic tephra related to the overlying alkalic flow forms the base of the Pliocene basalt sequence in R-12 (Appendix A). This tephra is a hydrovolcanic deposit characterized by fine-grained, well-stratified deposits made up of basaltic glass. Hand-sample analysis indicates that much of the basaltic glass remains unaltered, even though the basaltic tephra is a fully saturated unit within the upper perched horizon at R-12. This tephra occurs in drill hole R-9 as well (Table 3.5-1), but is considerably thinner in R-12 (2.7 ft) than in R-9 (7.8 ft). The tephra has previously been considered part of the old alluvium of Griggs (1964, 8795), but is included with basalt of the Cerros del Rio volcanic field in this report.

Table 3.5-1
Comparison of Basalt Flow Units Within R-12 and R-9

Correlated Flows and Tephra	R-12					R-9				
	Depth		Elevation		Thickness	Depth		Elevation		Thickness
	Top	Base	Top	Base		Top	Base	Top	Base	
upper tholeiite flow	131	260.5	6370	6240	129.5	10	118	6374	6266	108
lower tholeiite flow	260.5	342.3	6240	6158	81.8	118	180	6266	6204	62
upper alkalic flow	342.3	419.2	6158	6076	76.9	180	206	6204	6178	26
lower alkalic flow	419.2	488.9	6076	6012	69.7	206	282	6178	6102	76
lower alkalic tephra	488.9	491.6	6012	6009	2.7	282	289.8	6102	6094	7.8
Miocene flow	784	>886	5717	<5615	>102	686.4	>710	5698	<5674	>24

Notes: 1. All data are in feet.

2. Flow units in R-12 have well-defined vesicular and clay-rich boundaries, but flow units in R-9 are clay-poor and therefore not as well defined.

3. The upper tholeiite flow in R-12 consists of two texturally distinct flows.

3.6 Old Alluvium (491.6- to 545-ft depth)

The term "old alluvium" was used by Griggs (1964, 8795) to describe distinctive alluvium consisting of unconsolidated sands and gravels deposited on the upper pediment surface of the Puye Formation during the Late Pliocene, prior to emplacement of the Bandelier Tuff. Dethier (1997, 49843) recognized fluvial and lacustrine units, correlative with Griggs' (1964, 8795) old alluvium, in White Rock Canyon. Old alluvium at R-12 consists of three distinct deposits: a basal gravelly sandstone, a middle deposit of mostly claystone, and an upper conglomerate.

The upper conglomerate, between 491.6- and 519.1-ft depth, is dominated by silty sand at its top and base that sandwiches a sandy conglomerate with rounded to well-rounded pebbles to 37-mm diameter. In its upper part, the pebbles are mostly volcanic, but in its lower part gneiss and quartzite pebbles dominate. The dominance of large, rounded clasts of nonvolcanic origin establishes the upper conglomerate as a late Pliocene axial deposit of the ancestral Rio Grande. These deposits of the ancestral Rio Grande are younger than those of the Totavi Lentil of the Puye Formation, but similar in origin.

The middle portion of the old alluvium, from 519.1- to 535.5-ft depth, is a bedded silty claystone, with very fine-grained sand to silt in the upper part. This clay-rich unit forms the hydrologic barrier that perches the zone of saturation above 520-ft depth in R-12 (see Section 4.1 of this report). This fine-grained and clay-rich deposit formed in a lacustrine environment. A distinct rise in the natural gamma signal at ~515- to 520-ft depth (Figure 5.7-2) is probably related to the abundance of clay in this part of the old alluvium. Analysis of a sample from this interval by QXRD (Table 3.0-1) shows that more than half of the sample consists of clays (54% smectite and 8% kaolinite). A small amount of zeolite is also present, but the high clay content is the principal feature that accounts for the role of this unit in supporting perched water in the strata above. The clay component of this sample is unique among those analyzed in R-12 for its high kaolinite abundance (8% of the total sample, whereas other sediments have at most 1% and generally only trace amounts). This contrast with the deeper sediments can be seen within the kaolinite column in Figure 3.6-1. The high concentration of kaolinite has also been observed in alluvium developed above the Bandelier Tuff in Los Alamos Canyon [drill hole LAOI(A) 1.1] and may represent a distinctive aspect of alluvial deposits in the region.

The lower deposit of old alluvium, from 535.5- to 545-ft depth, is gravelly sandstone that is lithologically similar to the underlying fanglomerate facies of the Puye Formation, except that basalt clasts rather than dacite predominate within the alluvium. In contrast, basalt clasts are virtually absent within the Puye fanglomerates, particularly within the upper part. Old alluvium within R-9 is entirely equivalent to this lower deposit of R-12 but is considerably thicker (39.2 ft vs. 9.5 ft).

3.7 Puye Formation (fanglomerate facies; 545- to 784-ft depth)

The fanglomerate facies of the Puye Formation in drill hole R-12 consists of tuffaceous volcanogenic sediments, similar to those described within the Puye Formation to the north by Waresback (1986, 58715). Dethier (1997, 49843) found interstratified fanglomerate and axial river gravel facies of the Puye Formation in White Rock Canyon. All of the Puye sampled at R-12 is considered part of the fanglomerate facies. In comparison with the descriptions by Waresback (1986, 58715), the fanglomerates at R-12 are relatively fine-grained and probably represent distal deposits, far from the volcanic sources of the sediments.

In both R-12 and R-9, the Puye fanglomerate is characterized by reworked tuffaceous sandstones and gravels interbedded with sandstones and fine pebble gravels made up of crystalline volcanic detritus derived from the Tschicoma Formation. The tuffaceous materials (reworked pumices and volcanic ash) in the upper part of the Puye Formation are vitric whereas the lower half of the formation contains argillic tuffaceous sandstones and gravels, altered ash beds, and sands with abundant clay matrix. These differences, defined principally by the transition from preserved glass to extensive smectite development, are quantified by QXRD in Table 3.0-1 and illustrated in Figure 3.6-1. The major vitric interval occurs above 666-ft depth and the major zone of clay alteration occurs below 712.5-ft depth; the interval from 666 to 712.5 ft contains dacitic sandstones with abundant crystalline detritus that contained relatively little glass that could alter to form clays. These intervening dacitic sandstones in several respects are transitional between the upper and lower Puye units, but the loss of glass and alteration to clays places this unit mineralogically within the lower Puye Formation.

3.7.1 Upper Puye Formation (545- to 666-ft depth)

Above 666-ft depth, many volcanic fragments within the sediment are vitric, and the rock consists of poorly consolidated sand, pebbly sand, and gravel derived principally from rhyodacitic to dacitic rocks of the Tschicoma Formation. Vitric materials include rare crystal-rich pumice with varied phenocryst assemblages (plagioclase-orthopyroxene-clinopyroxene, plagioclase-amphibole-clinopyroxene), but most of the glass content is apparently within the groundmass of many of the dacite to rhyodacite clasts. Petrographic analyses of samples from both R-9 and R-12 demonstrate that many of the pebbles were derived from an early Pliocene rhyodacite exposed in the headwaters of Rendija Canyon. However, thin sections of pebbles from these deposits indicate the volcanic detritus is highly varied and represents material derived from perhaps three to five Tschicoma volcanic centers. These lithologies range from relatively siliceous and hydrous quartz-biotite-amphibole rhyodacite to anhydrous and less siliceous two-pyroxene dacites lacking quartz or any hydrous phases.

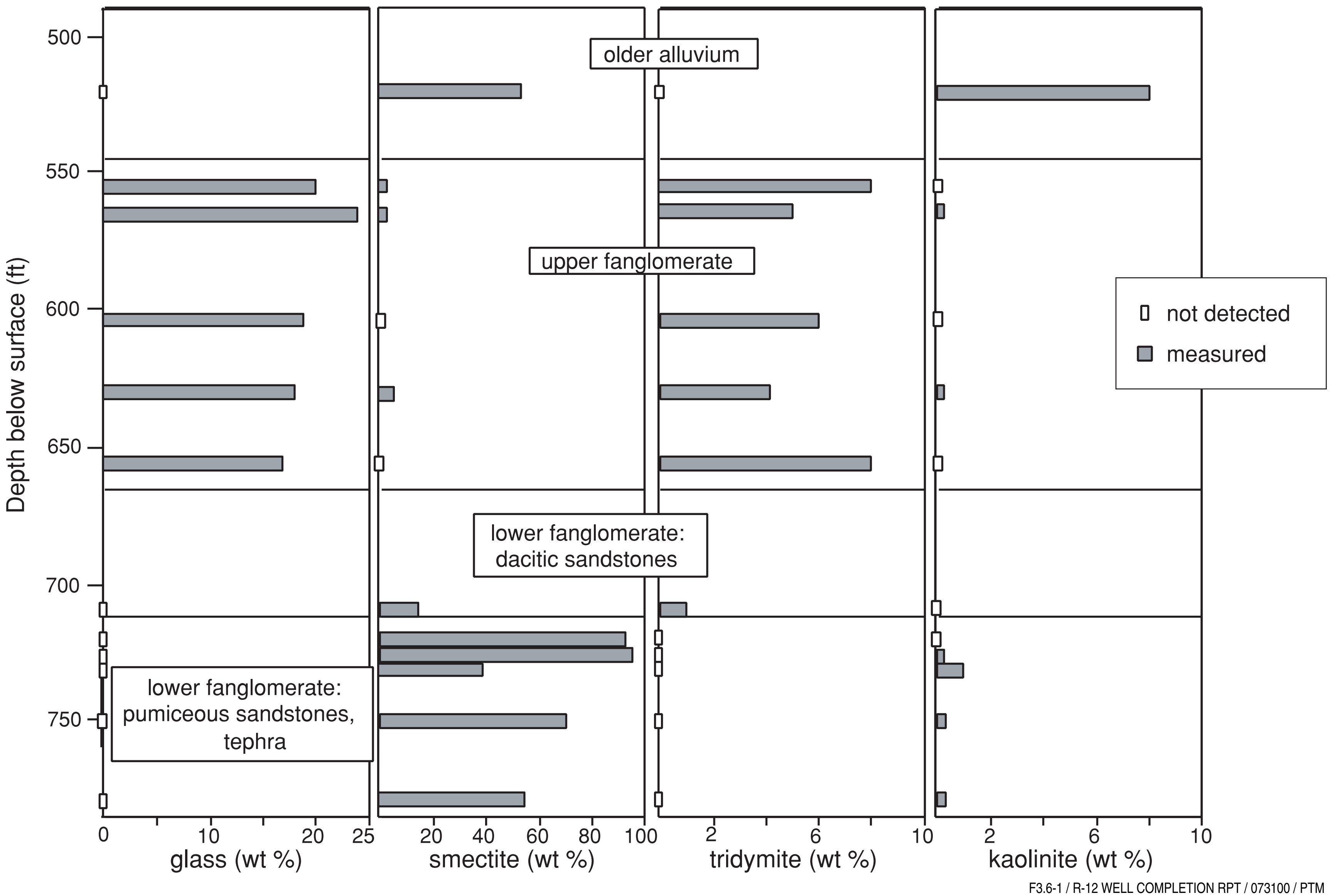


Figure 3.6-1. **Abundances of glass, smectite, tridymite, and kaolinite in representative samples from the old alluvium and the Puye Formation in R-12. Note variable scales of horizontal axes (weight percent; QXRD data from Table 3.0-1).**

3.7.2 Lower Puye Formation (666- to 784-ft depth)

The lower Puye Formation in R-12 contains two subunits. The upper subunit, from 666- to 712.5-ft depth, consists of a series of sandstones with predominantly crystalline dacitic detritus and subordinate once-vitric (now clay-altered) pumice. The lower subunit, from 712.5- to 784-ft depth, consists almost entirely of once-vitric (now clay-altered) pumiceous sands and tephras with little detritus from crystalline dacitic sources.

3.7.2.1 Dacitic Sandstones of the Lower Puye Formation (666- to 712.5-ft depth)

From 666- to 712.5-ft depth, the lower Puye Formation consists of pebbly sandstone with many of the same dacite to rhyodacite lithologies of the overlying fanglomerate but without remnant glass in any of the once-vitric detritus. The glass that had been present has altered to clays. Some of the coarser dacitic clasts have adhering sandstone detritus in a clay matrix. Chemical data from the representative dacitic sandstone sample (sample R12-710D, Table 3.0-2) are in many respects transitional between the overlying fanglomerates and the underlying pumiceous and tephra units of the Puye. The same is true of the moisture content, which ranges from 9% to 13% for this unit, compared with values ≤8% for the overlying fanglomerates and 20% to 42% for the underlying pumiceous sands and tephras (Appendix B). The QXRD data show that the representative sample from the dacitic sandstones (R12-710D) differs only from the upper Puye Formation in the relatively higher abundance of feldspar, cristobalite, and clay (Table 3.0-1). However, the petrographic data indicate a complete absence of the quartz-bearing intermediate lavas that occur in variable amounts throughout the upper Puye Formation (Appendix B).

3.7.2.2 Pumiceous Sands and Tephras of the Lower Puye Formation (712.5- to 784-ft depth)

Below 712.5-ft depth, the Puye Formation at R-12 consists of consolidated sandstone to pebbly sandstone characterized by abundant pumice fragments. These pumice fragments are generally altered to clay (Figure 3.6-1). Clasts within the older fanglomerate are almost entirely dacitic rocks derived from sources that do not include quartz-bearing lithologies similar to the rhyodacites from Rendija Canyon. The altered pumice is generally aphyric with rare plagioclase phenocrysts. Detrital crystals in the matrix supporting the pumice fragments are varied and include olivine, amphibole, biotite, plagioclase, quartz, and rare occurrences of other minerals (e.g., muscovite in pumiceous sandstone at 730.6-ft depth; chlorite in sandstones at 751.5- and 779.5-ft depth). Samples analyzed in thin section from 730.6- and 779.5-ft depth includes abundant clasts of highly altered dacitic to basaltic lithologies plus altered pumice in clay matrix. Small amounts of carbonate cement occur in the two lowest samples, at 751.5- and 779.5-ft depth.

Two argillic beds of primary to slightly reworked volcanic ash that are a few inches to about 1-ft thick occur within the older fanglomerate of the Puye Formation in both R-12 and R-9. The upper ash bed in R-12 and the overlying and underlying pumiceous sandstones were analyzed by QXRD (samples R12-720, R12-726.4, and R12-730.6; Table 3.0-1 and Figure 3.6-1). Clay abundances are very high (93% to 96%) in both the ash bed and the overlying pumiceous sandstone, but considerably lower in the underlying sandstone. These differences and the complete absence of glass in all samples from the lower fanglomerate indicate that the extent of clay development is controlled by the initial abundance of glass before alteration. Intervals in the sedimentary sequence with abundant detrital quartz or feldspar (e.g., sample R12-730.6) limit the amount of glass available for clay development.

Table 3.0-1 and Figure 3.6-1 show that in addition to the loss of glass with alteration to smectite in the lower fanglomerate, there is a correlative loss of the silica polymorph tridymite. Since many source lithologies for both horizons contain tridymite, this difference is probably a consequence of alteration rather than a primary change in source-rock mineralogy. Tridymite is unstable in low-temperature aqueous systems and the QXRD data in R-12 suggest that tridymite has been lost from samples in the lower Puye volcaniclastic series by dissolution.

3.7.3 Relations between the Puye Formation at R-9 and R-12

The upper Puye Formation contains thicker and coarser gravel beds than those of conglomerates within the lower Puye Formation, and thus is coarser overall. The upper Puye Formation is also much less pumiceous, and generally unconsolidated because of its lack of clay alteration. Although a distinct middle-zone with glass- and clay-poor dacitic sandstones was not identified at R-9, the contacts within the major fanglomerate facies of the Puye Formation and elevations of the tephra units consistently differ by only 12 to 25 ft between R-12 and R-9 if the dacitic sandstone in R-12 is associated with the lower Puye Formation (Table 3.7-1; Figure 3.5-2). The justification for including the dacitic sandstone within the lower Puye Formation lies in the common alteration history throughout the sequence below 666-ft depth in R-12, where no remnant glass is preserved and maximum clay development correlates with the quantity of altered glass.

Table 3.7-1
Comparison of the Contacts for
Fanglomerate Facies of Puye Formation in Drill Holes R-12 and R-9

Correlated Strata	R-12					R-9				
	Depth		Elevation		Thickness	Depth		Elevation		Thickness
	Top	Base	Top	Base		Top	Base	Top	Base	
upper Puye Formation	545	666	5954.6	5833.6	121	329	539	6054	5844	210
lower Puye Formation	666	784	5833.6	5715.6	118	539	686.4	5844	5696.4	147.4
dacitic sandstone	666	712.5	5833.6	5787.1	46.5	539	587	5844	5795.8	48
upper tephra	726.1	726.4	5773.5	5773.2	0.3	595.1	595.25	5787.7	5787.55	0.15
lower tephra	746.1	746.4	5753.5	5753.2	0.3	606.2	607.2	5776.6	5775.6	1.0

Note: All data are in feet.

With the incorporation of the dacitic sandstone in the lower Puye Formation at R-12, the apparent dip of internal contacts within the Puye Formation, between R-9 and R-12, is less than 0.5 degrees (Figure 3.5-1). The excellent correspondence among layers within the fanglomerate facies demonstrates the tabular nature for these deposits, and suggests that younger and older fanglomerate are probably widely correlatable units. A marked, sudden increase in alteration across a contact into an older unit, such as that observed across the contact into the lower Puye Formation, may be taken to indicate a significant age difference across the contact. On this basis, the lower Puye Formation may have a late Miocene depositional age, closer to that of underlying basalt rather than to the upper Puye Formation.

3.8 Late Miocene Basalt (784- to >886-ft depth)

The deepest unit penetrated in R-12 is basalt that extends from 784 ft to >886 ft (total depth). The basalt is slightly vesicular, with clay filling some vesicles below 830-ft depth. The basalt is coarse-grained, with a gabbroic texture and olivine phenocrysts of ~1.5 mm. The olivine grains are extensively altered to iddingsite but commonly retain small cores of unaltered material. All original voids in the groundmass are filled with carbonate minerals. This basalt correlates with a tholeiitic basalt in R-9 that has been dated at 8.5 to 8.6 Ma (Broxton et al. 2000, 66599). A chemical analysis of this basalt from above the clay alteration depth, at 810 ft is listed in Table 3.0-2. This analysis is slightly more calcic than the analysis of the Miocene basalt in R-9, but the similarities in composition are more prominent than this minor difference. The surface of the Miocene basalt is 18 ft higher in R-12 than in R-9, in contrast to the consistently lower elevations of all Pliocene basaltic flow surfaces in R-12 compared with R-9.

4.0 OCCURRENCES OF GROUNDWATER

Two saturated zones were encountered during R-12 drilling operations. The upper of these two zones is a perched groundwater zone, and the lower is associated with the regional aquifer.

4.1 Perched Groundwater

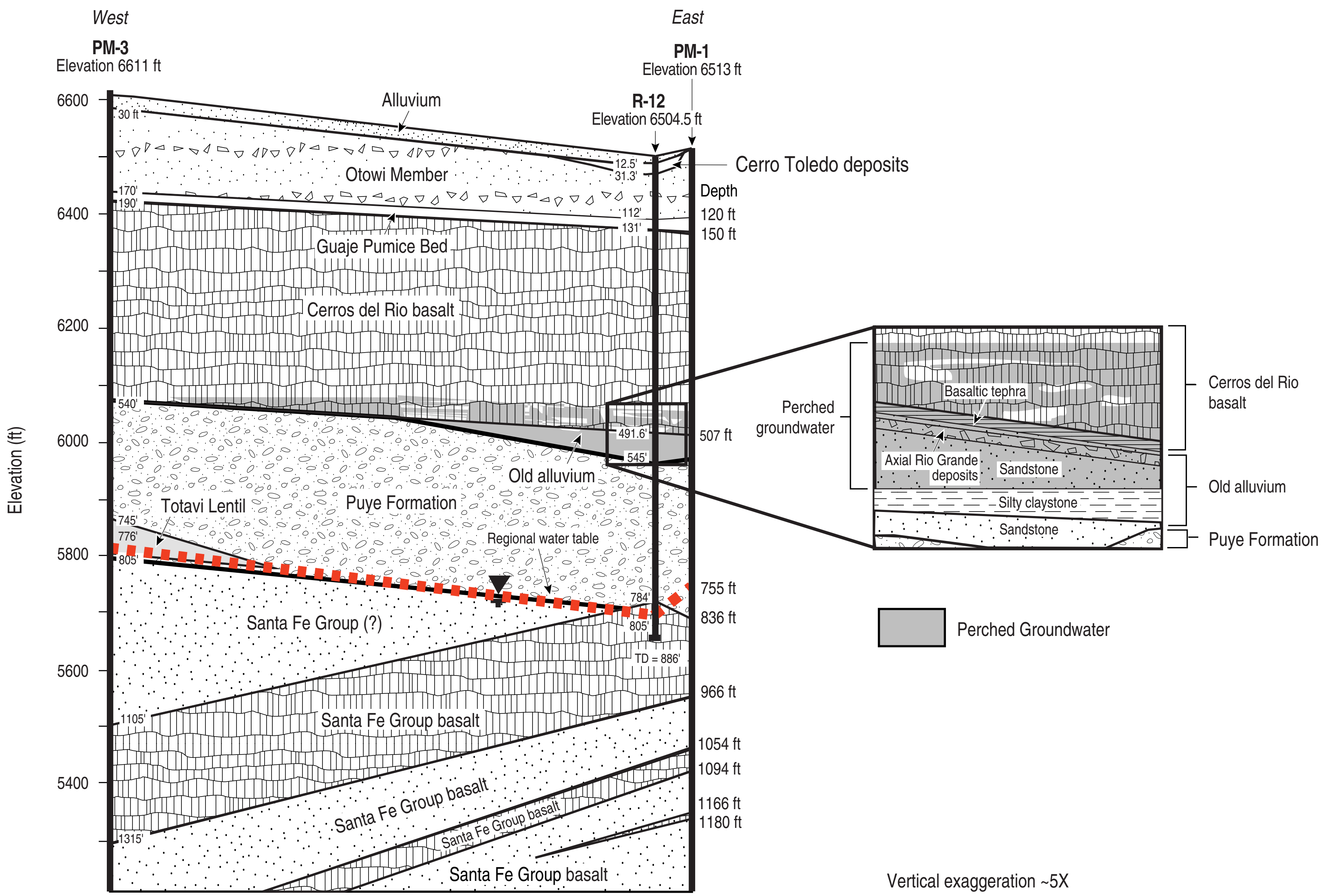
A thick perched zone was encountered in the lower part of the basaltic rocks of the Cerros del Rio volcanic field and in the underlying old alluvium (Figure 4.1-1). This perched zone was first recognized in 1964 during the installation of water supply well PM-1 (Cooper et al. 1965, 8582), although its vertical extent was not specified. During the drilling of R-12, water was first encountered at a depth of 443 ft, and the water level quickly rose to 424 ft. The claystone subunit of the old alluvium forms the perching layer.

The basalt flows making up the upper part (443 to 488.9 ft) of the perched zone are typically fractured and yielded water rapidly to the borehole. Interspersed within the saturated zone, thin zones of massive unfractured basalt typically yielded dry core or cuttings, but the borehole always produced significant water when deeper, fractured basalts were penetrated. Bentonite seals were placed several times in dry, unfractured, massive basalts in the belief that the bottom of the perched zone had been reached. However, water quickly filled the borehole to a static water level of 424 ft each time new fractured basalts were encountered. These relations suggest that all the groundwater in these basalts is part of a single perched zone in which the water-producing zones in the basalt are connected by fractures (Figure 4.1-1). The dry, unfractured, massive basalts within the water-producing zones probably represent regions of low permeability that are crossed by fractures outside the volume of the borehole. The basaltic tephra (488.9 to 491.6 ft), which acts as a perching layer for groundwater in R-9, is saturated in R-12.

The lower part of the perched zone (491.6 to 519 ft) occurs within the sand and silt deposits and the axial Rio Grande gravels of the upper subunit of the old alluvium. Permeability in this part of the perched zone is probably controlled by the matrix properties of these sedimentary deposits. Perched water within these sedimentary deposits also has a static water level of 424 ft, indicating that it is hydraulically connected with groundwater in the overlying basalts.

This groundwater is perched at a depth of 519 ft atop the claystone subunit of the old alluvium. This claystone unit is a 16-ft-thick lacustrine deposit that contains abundant smectite and kaolinite (see Section 3.6 of this document). The lateral extent of this lacustrine deposit is uncertain. Similar deposits are exposed at approximately the same stratigraphic level below Cerros del Rio basalt north of State Highway 502, 2.5 km northeast of R-12, and on the north side of Guaje Canyon west of its confluence with Los Alamos Canyon. However, no lacustrine deposit is present within the old alluvium at R-9, 1 km north of R-12.

A seal to isolate the perched zone from the rest of the borehole was created by driving the 10-3/4-in.-diameter casing into the top of the lacustrine deposits at a depth of 519 ft. This natural clay seal prevented downward migration of water to potential deeper perched water zones and the regional aquifer and allowed representative water samples to be collected from deeper zones.



F4.1-1 / R-12 WELL COMPLETION RPT / 060900 / PTM

Figure 4.1-1. East-west cross section showing geologic relationships and groundwater occurrences in lower Sandia Canyon

The observations of water-level rise after the perched zone was first penetrated within the Cerros del Rio basalts suggest two different interpretations. One interpretation is that groundwater is confined at 443-ft depth by massive basalt within the interior of the lower alkalic basalt. In this interpretation, the basalt interior acts as a low-permeability confining bed because it contains few interconnected fractures. A second interpretation is that the perched groundwater is not confined. In this interpretation, the top of saturation is represented by the static water level of 424 ft and groundwater did not enter the borehole until water-bearing fractures were intersected at a depth of 443 ft.

Depending on which of the interpretations described above is applied, the saturated thickness of perched groundwater in the Cerros del Rio basalt and old alluvium at R-12 ranges from 76 to 95 ft. This saturated thickness is the greatest yet recognized for intermediate-depth perched water in the eastern part of the Pajarito Plateau.

A second perched zone of saturation may have been penetrated in R-12, but observations collected during drilling operations suggest this possible zone of saturation produced little if any water.

Core with a high moisture content was encountered in clay-rich, tuffaceous, sedimentary rocks in the lower part of the Puye Formation. The moist core was returned from depths of 736 to 741 ft, but at the end of the drilling day no measurable water was present at a depth of 741 ft. However, a downhole moisture probe indicated the presence of moisture at a depth of 733.80 ft after the borehole rested overnight. Collection of a water sample was not attempted in the belief that regional saturation had been reached based on projections from supply well PM-1 (projected depth to the regional water table was 740 ft) and that further opportunities for sampling would be available as the borehole was deepened to accommodate a bailer. However, the borehole failed to yield water as drilling progressed, and no water sample was obtained. Based on information currently available, it cannot be determined whether saturated conditions are present in the clay-rich materials in the lower Puye Formation or if an erroneous indication of saturation occurred when the tip of the moisture probe became embedded in formational units and indicated the presence of moist clays. Furthermore, absence of saturation at a depth of 741 ft is suggested by the lack of water circulating out of the hole when the air-circulation system was started and as drilling operations proceeded beyond 741 ft.

4.2 Regional Aquifer

The regional water table was encountered at a depth of 805 ft (elevation 5694.6 ft) in fractured basalt of the Santa Fe Group. Groundwater at the top of the regional saturated zone is unconfined, and the static water level occurs at about the same elevation as that encountered in well R-9 (elevation 5694.8 ft). This saturated zone is believed to represent the regional aquifer because its water quality is similar to that found in nearby supply wells PM-1 and PM-3, and in test well (TW)-3. In addition, the elevation at the top of this zone is lower than static water levels (under nonpumping conditions) of regional groundwater in supply wells PM-1 (5758 ft) and Otowi-1 (5724 ft), and it is lower than the elevation predicted for the regional water table (5795 ft) based on regional water-table studies (Figure 1.0-1).

The higher static water levels in nearby water supply wells are probably due to their long screen lengths, allowing multiple zones to contribute to a composite hydraulic head in an area of upward gradient. PM-1 is screened over a 1554-ft interval (Cooper et al. 1965, 8582). The higher static water levels for the supply wells suggest that higher head zones occur in the regional aquifer at depths greater than those penetrated by R-12 and R-9. If so, the regional aquifer may have upward hydraulic gradients in this part of the Pajarito Plateau.

The change in static water level at the top of the regional saturated zone in the R-12 borehole was recorded for a nine-month period from June 16, 1998, to March 8, 1999. Water-level measurements were taken with a transducer that was placed inside a temporary 4-in. polyvinyl chloride (PVC) casing and screen. Water level and atmospheric pressure were recorded on a 15-minute interval. No water-level measurements were taken over the period from October 1, 1998, to October 15, 1998. During this time period the transducer was removed from the temporary well so that a bailer could be used to develop the well and collect groundwater samples. Figure 4.2-1 shows the relationship between atmospheric pressure and the static water level in the regional aquifer. A rise in atmospheric pressure results in a lowering of the static water level. Conversely, the static water level rises during periods when the atmospheric pressure decreases. The water level record collected in borehole R-12 indicates the static water level at the top of the regional saturated zone rose a distance of approximately 0.5 ft over the nine-month period of measurement despite pumpage from nearby water supply well PM-1.

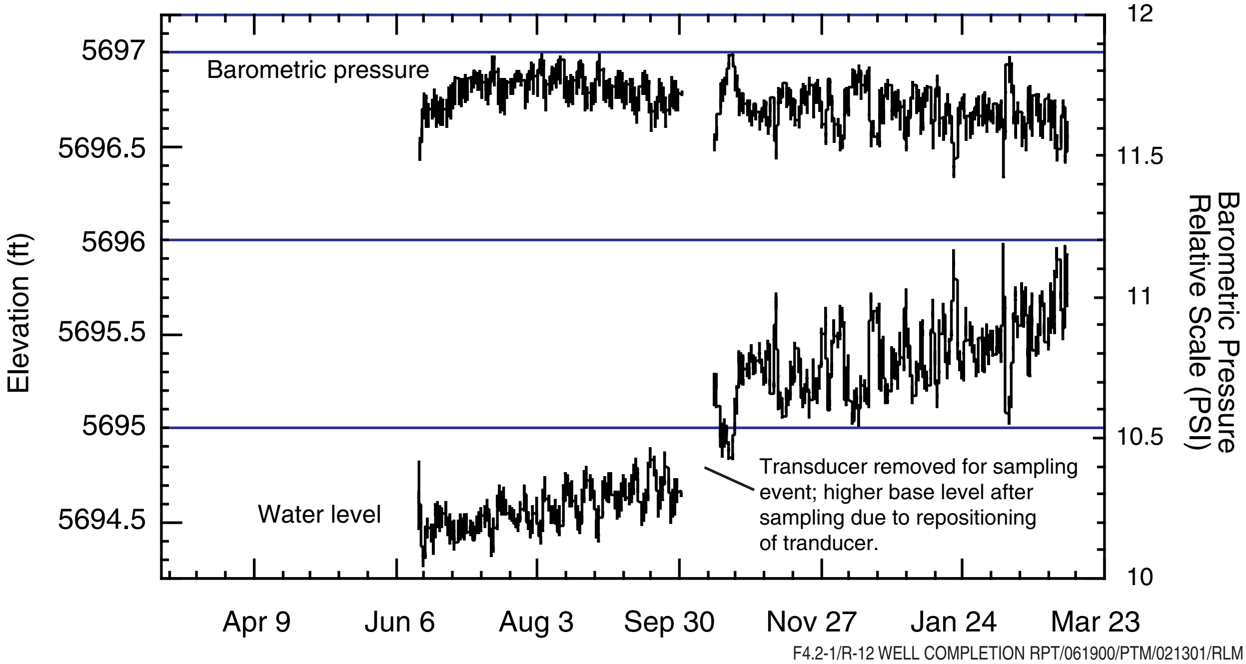


Figure 4.2-1. Water level and barometric pressure for regional aquifer in borehole R-12 from June 16, 1998, to March 8, 1999

5.0 SAMPLING AND ANALYSIS

Discharges within Sandia Canyon and Mortandad Canyon may have impacted water quality at R-12. Contaminants of concern in Sandia Canyon include tritium and nitrate (Environmental Surveillance and Compliance Programs 1997, 56684). For several decades treated sewage has been discharged from the Technical Area (TA) 3 sanitary system into upper Sandia Canyon. Surface water samples collected in upper Sandia Canyon suggest that this discharge may have contained tritium until the early 1980s (Rogers 1998, 59169). Tritium activities up to 18,000 pCi/L have been observed at surface water sampling station SCS-2 (Rogers 1998, 59169), 5 km west of R-12.

Known groundwater contaminants within Mortandad Canyon west of R-12 include americium-241; cesium-137; plutonium-138; plutonium-239,240; strontium-90; tritium; uranium-235; uranium-238; and other inorganic solutes (Environmental Surveillance and Compliance Programs 1997, 56684; Rogers 1998, 59169). Tritium activities up to 1,000,000 pCi/L have been observed in alluvial groundwater within Mortandad Canyon in the past.

Known groundwater contaminants in upper Los Alamos Canyon include americium-241; cesium-137; plutonium-238; plutonium-239,240; strontium-90; tritium; uranium-235; and uranium-238 (LANL 1995, 50290).

5.1 Contaminant Characterization of Core and Cuttings

Samples of core and cuttings were collected from R-12 and analyzed for metals and radionuclides. Results of chemical and radiochemical analyses are used to determine both naturally occurring elements and contaminant distributions within R-12. Organic compounds were not identified as contaminants of concern at R-12, based on sediment and water sampling conducted by the Laboratory in upper Sandia Canyon (Environmental Surveillance and Compliance Programs 1997, 56684).

5.1.1 Methods

Fourteen samples of core and cuttings were collected for geochemical and contaminant characterization (Table 5.1-1). Approximately 500 to 1000 g of core or cuttings samples were placed in appropriate sample jars in protective plastic bags before they were shipped to analytical laboratories.

Samples of core and cuttings were analyzed using analytical methods specified by the US Environmental Protection Agency (EPA) (1987, 57589). Solid samples were partially digested using hot HNO_3 (EPA method 3050) before metal analyses. Samples of core and cuttings were shipped to Paragon Analytics, Inc., in Fort Collins, Colorado, for metal and radionuclide analyses. Analyses of aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, potassium, selenium, silver, sodium, thallium, vanadium, and zinc were determined by inductively coupled plasma emission spectroscopy (ICPES). Concentrations of uranium in core samples were determined by using laser-induced kinetic phosphorimetric analysis (LIKPA). Mercury was analyzed by cold vapor atomic absorption (CVAA). Core samples were washed with deionized water for 16 hr before anion analyses. Bromide, chloride, fluoride, nitrate, and sulfate contents were determined by ion chromatography (IC). Total cyanide content was determined by colorimetry. The precision limits for major anions and trace elements were generally ±10%.

Radionuclide activities in core samples were determined by alpha spectrometry (americium-241; plutonium-238; plutonium-239,240; uranium-234; uranium-235; and uranium-238); gamma spectrometry (cesium-137 and gamma-emitting isotopes); and gas proportional counting (strontium-90) at Paragon Analytics, Inc. Sample duplicates were collected and analyzed in accordance with EPA procedures.

Field screening for volatile organic compounds (VOCs) was conducted using a photoionization detector (PID) instrument. No VOCs were detected with the field instrument.

Table 5.1-1
Radionuclide Activities in Samples of Core and Cuttings from Borehole R-12

Depth (ft)	25–25.5	31.5–32.5	122–125	135–136	431–438	455–456.5	520–521.9
Geologic Unit	Bandelier Tuff	Bandelier Tuff	Bandelier Tuff	CR basalt[a]	CR basalt	CR basalt	old alluvium
Strontium-90[b]	0.01 ± 0.44	-0.22 ± 0.46	-0.20 ± 0.46	0.06 ± 0.44	-0.12 ± 0.49	0.05 ± 0.11	0.08 ± 0.11
Cesium-137	-0.053 ± 0.057	0.043± 0.067	0.006± 0.079	-0.013± 0.037	-0.014 ± 0.042	0.001± 0.035	-0.034 ± 0.077
Plutonium-238	0.0146 ± 0.0080	0.0000 ± 0.0064	-0.0086± 0.0050	0.0104 ± 0.0068	0.0092 ± 0.0138	-0.024± 0.020	0.021± 0.028
MDA[c]	0.026	0.036	0.034	0.025	0.028	0.088	0.056
Plutonium-239,240	0.0167 ± 0.0079	0.092 ± 0.018	0.0131 ± 0.0072	0.0214 ± 0.0089	0.108 ± 0.034	0.004 ± 0.020	0.0113 ± 0.0194
MDA	0.020	0.0099	0.024	0.022	0.022	0.058	0.032
Americium-241	0.0026 ± 0.0050	0.036 ± 0.013	0.0159 ± 0.0080	0.018 ± 0.011	0.062 ± 0.046	0.0063 ± 0.0194	0.024 ± 0.030
MDA	0.025	0.025	0.026	0.042	0.049	0.048	0.057
Uranium-234	1.63 ± 0.24	1.69 ± 0.24	3.97 ± 0.50	0.397 ± 0.080	0.462 ± 0.086	0.498 ± 0.108	1.089 ± 0.190
MDA	0.018	0.028	0.026	0.025	0.021	0.026	0.041
Uranium-235	0.083 ± 0.032	0.060 ± 0.026	0.163 ± 0.340	0.0276 ± 0.0192	0.0241 ± 0.0162	0.0209 ± 0.0192	0.081 ± 0.040
MDA	0.015	0.019	0.018	0.020	0.0170	0.022	0.031
Uranium-238	1.73 ± 0.24	1.80 ± 0.24	4.19 ± 0.54	0.415 ± 0.082	0.547 ± 0.098	0.446 ± 0.100	1.082 ± 0.188
MDA	0.021	0.025	0.02	0.027	0.024	0.026	0.038
Uranium (LIKPA[d]) (mg/kg)	1.35 ± 0.19	3.09 ± 0.42	0.86 ± 0.12	5.45 ± 0.75	1.33 ± 0.18	1.03 ± 0.14	2.08± 0.29
MDC[e]	0.05	0.49	0.48	0.49	0.48	0.47	0.05
Gross Alpha	2.51 ± 0.68	1.73 ± 0.57	1.44 ± 0.55	3.0 ± 1.7	7.6 ± 3.2	6.5 ± 3.0	10.2 ± 3.2
Gross Beta	1.90 ± 0.58	1.60 ± 0.57	1.73 ± 0.57	1.7 ± 1.8	4.4 ± 2.1	<3.2 (MDA)	8.0 ± 2.5
Gross Gamma	14.46 ± 1.09	13.72 ± 1.01	24.76 ± 1.74	3.01 ± 0.36	4.02 ± 0.35	3.87 ± 0.36	3.86 ± 0.33
MDA	0.69	0.58	0.82	0.44	0.34	0.38	0.30
Strontium-90[d]	0.12 ± 0.49	-0.13 ± 0.43	-0.13 ± 0.49	0.06 ± 0.37	0.30 ± 0.59	-0.06 ± 0.35	0.03± 0.36
Cesium-137	-0.023 ± 0.029	0.007± 0.065	0.023± 0.061	0.061± 0.043	-0.002 ± 0.038	0.000 ± 0.049	0.029 ± 0.038

Table 5.1-1 (continued)

Depth (ft)	555–559	555–559 (dup[f])	567–569	791–792.5	800–801.5	812–814.6	812–814.6 (dup)
Geologic Unit	Puye Formation[g]	Puye Formation	Puye Formation	SFG basalt[h]	SFG basalt	SFG basalt	SFG basalt
Plutonium-238	0.017± 0.026	0.007 ± 0.022	0.0084 ± 0.0194	0.0147 ± 0.0184	0.0017 ± 0.0110	0.0132± 0.0146	0.0036 ± 0.0156
MDA	0.050	0.056	0.040	0.035	0.030	0.024	0.040
Plutonium-239,240	0.0037 ± 0.0190	-0.0024 ± 0.0194	0.0018 ± 0.0200	-0.0096 ± 0.0106	0.0094 ± 0.0122	0.027 ± 0.020	-0.0007 ± 0.0112
MDA	0.037	0.051	0.0180	0.039	0.019	0.028	0.029
Americium-241	0.084 ± 0.050	0.112 ± 0.066	0.027 ± 0.026	-0.0031 ± 0.0088	0.067 ± 0.040	0.037 ± 0.032	0.097 ± 0.048
MDA	0.053	0.060	0.038	0.027	0.034	0.045	0.041
Uranium-234	0.746 ± 0.140	0.905 ± 0.160	1.162 ± 0.190	0.348 ± 0.090	0.252 ± 0.072	0.232 ± 0.068	0.173 ± 0.058
MDA	0.025	0.035	0.032	0.039	0.029	0.023	0.013
Uranium-235	0.048 ± 0.028	0.054 ± 0.032	0.061 ± 0.032	0.037 ± 0.026	0.038 ± 0.028	0.0188 ± 0.0190	0.047 ± 0.028
MDA	0.025	0.032	0.026	0.014	0.035	0.028	0.013
Uranium-238	0.742 ± 0.140	0.906 ± 0.160	1.155 ± 0.188	0.283 ± 0.078	0.322 ± 0.082	0.269 ± 0.074	0.190 ± 0.060
MDA	0.033	0.021	0.030	0.027	0.029	0.013	0.013
Uranium (LIKPA) (mg/kg)	1.50 ± 0.20	2.26 ± 0.31	2.26 ± 0.31	0.85[k]	0.97[i]	0.81[i]	0.57[i]
MDC	0.05	0.50	0.05				
Gross Alpha	1.44 ± 0.61	2.04 ± 0.68	1.58 ± 0.59	1.4 ± 1.2	2.2 ± 1.1	1.57 ± 0.32	1.61 ± 0.32
Gross Beta	1.20 ± 0.54	1.29 ± 0.53	0.98 ± 0.51	0.38 ± 0.96	1.00 ± 0.74	DNR[j]	DNR
Gross Gamma	6.75 ± 1.12	8.89 ± 1.50	7.99 ± 1.35	2.17 ± 0.41	2.15 ± 0.41	DNR	DNR
MDA	0.20	0.35	0.36	0.29	0.29		

Notes: 1. pCi/g.

2. Error of two standard deviations is reported.

[a] CR basalt = Cerros del Rio basalt.

[b] Radionuclides and parameters analyzed by Paragon Analytics, Inc.

[c] MDA = minimum detectable activity.

[d] LIKPA = laser-induced kinetic phosphorimetric analysis.

[e] MDC = minimal detectable concentration.

[f] dup = duplicate sample.

[g] Puye Formation = fanglomerate facies of the Puye Formation.

[h] SFG basalt = Santa Fe Group basalt.

[i] Calculated from uranium-238 activity.

[j] DNR = data not received yet.

5.1.2 Results

Table 5.1-1 provides radionuclide activities in core and cuttings from R-12. Isotopes of uranium (uranium-234, uranium-235, and uranium-238); gross alpha; gross beta; and gross gamma generally are detected at activities greater than their minimum detectable activities (MDAs) in most core samples. Activities of gross alpha, gross beta, and gross gamma in samples of core and cuttings are greater than 1 pCi/g, where measurable, and vary with depth (Table 5.1-1).

Activities of isotopic uranium are greatest in samples collected from the Bandelier Tuff, reflecting the high total uranium in this unit (Ryti et al. 1998, 58093). Lower activities of uranium-234, uranium-235, and uranium-238 were found in samples collected from Cerros del Rio basalt, Puye Formation, and Santa Fe Group basalt. This suggests that little if any Laboratory contaminants are present in these samples.

Activities of americium-241; cesium-137; plutonium-238; plutonium-239,240; and strontium-90 generally are less than detection in the samples of core and cuttings. Possible exceptions include detectable plutonium-239,240 within cuttings collected in the 31.5- to 32.5-ft interval and in the 431- to 438-ft interval (Table 5.1-1). The 31.5- to 32.5-ft interval is within the uppermost part of the Otowi Member. The 431- to 438-ft interval is just above the saturated zone encountered at a depth of 443 ft. Further comparisons with background data will be made when ongoing background studies for basalts are completed.

Samples of core and cuttings were analyzed for metals including aluminum, antimony, arsenic, barium, beryllium, cadmium, calcium, cobalt, copper, iron, lead, manganese, molybdenum, nickel, potassium, selenium, silver, sodium, thallium, uranium, vanadium, and zinc; however, they are not contaminants of concern in Sandia Canyon. Transition metals, including cobalt, copper, manganese, nickel, and iron, occur naturally within the basalt flows (concentrated within oxide and silicate minerals) at concentrations above those for the Bandelier Tuff. Background distributions of metals within basalt are being assessed and will be added to the Laboratory background data set.

5.2 Water Quality Determinations

Four groundwater samples were collected from two saturated zones encountered in R-12. Three of these samples were collected from the perched zone within the Cerros del Rio basalt (at 443 and 464 ft) and old alluvium (at 495 ft), and one sample was collected from the regional aquifer in Santa Fe Group basalt (at 805 ft). Samples were analyzed for inorganic and organic chemicals and radionuclides to determine natural solute and contaminant distributions within the different saturated zones.

5.2.1 Methods

Groundwater samples for inorganic and organic chemicals and radionuclides were collected using a stainless-steel bailer. Temperature, dissolved oxygen (DO), turbidity, pH, and specific conductance were determined onsite from an aliquot collected during field sampling. Both filtered and nonfiltered samples were collected for chemical and radiochemical analyses. Groundwater samples were collected for analyses of dissolved organic carbon (DOC); stable isotopes of hydrogen, oxygen, and nitrogen; major cations and anions; metals; organic compounds; and radionuclides. Aliquots of the samples were pressure-filtered (nitrogen gas) through a 0.45-µm Gelman filter and acidified with analytical-grade HNO_3 to a pH of 2.0 or less for metal and radionuclide analyses. DOC samples were filtered with a special 0.45-µm silver filter to eliminate biodegradation of organic solutes, which may bias analytical results. All groundwater samples collected in the field were stored at 4°C until they were analyzed. Alkalinity was determined in the laboratory using standard titration techniques.

Groundwater samples were analyzed using techniques specified in EPA SW-846 (EPA 1987, 57589) including IC for bromide, chloride, fluoride, nitrate, nitrite, phosphate, and sulfate; graphite furnace atomic absorption (GFAA) for trace elements (aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, calcium, cesium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, potassium, rubidium, selenium, silicon, silver, sodium, strontium, thallium, tin, titanium, vanadium, and zinc); colorimetry for total cyanide; CVAA for mercury; and ICPES for aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, calcium, chromium, cobalt, copper, iron, lead, magnesium, manganese, molybdenum, nickel, potassium, selenium, sodium, thallium, vanadium, and zinc. This work was performed by a contract laboratory, Paragon Analytics, Inc., and EES-1.

Radionuclide activity in groundwater was determined by liquid scintillation counting (LSC) for tritium; electrolytic enrichment for low-level tritium; LIKPA for uranium; alpha spectrometry for americium, plutonium, and uranium isotopes; gamma spectrometry for cesium-137 and other isotopes; and gas proportional counting for strontium-90. This work was performed by contract laboratories including Paragon Analytics, Inc., Teledyne, and the University of Miami.

Stable isotopes of oxygen (oxygen-18 and oxygen-16), hydrogen (hydrogen and deuterium), and nitrogen (nitrogen-15 and nitrogen-14) were analyzed by Geochron Laboratories (Cambridge, Massachusetts) and Coastal Science Laboratories, Inc. (Austin, Texas), respectively, using isotope ratio mass spectrometry (IRMS).

Laboratory blanks and field blanks were collected and analyzed in accordance with EPA and Laboratory procedures. The precision limits for major ions and trace elements were generally ±10%.

Groundwater samples collected at 443 ft within the uppermost portion of the perched zone in the basalt, and at 805 ft within the regional aquifer, were analyzed for semivolatile organic compounds (SVOCs) (polychlorinated biphenyls [PCBs] and pesticides) using gas chromatography-mass spectrometry by RECRA Weston. SVOCs were not detected in the groundwater samples from either of these zones. Groundwater samples collected from the two other perched zones were not analyzed for organic compounds.

The following sections focus on the distributions of inorganic chemicals (major cations and anions, nitrate, and ammonium) and radionuclides in groundwater encountered in R-12.

5.2.2 Results

5.2.2.1 Quality of Groundwater within Cerros del Rio Basalt and Santa Fe Group Basalt

Field-measured parameters for the borehole groundwater samples, including pH, temperature, specific conductance, and turbidity, are provided in Table 5.2-1. These parameters were measured at the time of sample collection when groundwater was in contact with the atmosphere. DO was also measured; however, DO values are not reported because of potential atmospheric contamination with the electrode and interferences from suspended particles contributing to very high turbidity values.

Table 5.2-2 provides analytical results for major ions and trace elements in filtered and nonfiltered samples collected from the two saturated zones in R-12. Bar plots for dissolved major ions and silica for the perched groundwater at R-12, R-9, POI-4, and Spring 9B are shown in Figure 5.2-1.

Table 5.2-1
Field-Measured Parameters for Groundwater Samples Collected at R-12

Geologic Unit	Cerros del Rio Basalt		Old Alluvium	Santa Fe Group Basalt
Depth (ft)	443	464	495	805
Date sampled	04/13/98	04/29/98	04/30/98	06/08/98
pH (standard units)	7.65	7.65	8.25	7.64
Temperature (°C)	14.2	15.5	16.0	18.9
Specific conductance (µSi/cm)	376	1381	365	279
Turbidity (NTU[a])	clear	os[b]	os	6

[a] NTU = nephelometric turbidity unit.

[b] os = off the scale because of very high turbidity values for open-borehole groundwater samples. The sample collected from the 443-ft zone was clear; however, the turbidity meter was not operating.

Table 5.2-2
Water Quality of Groundwater Samples Collected at Borehole R-12, Sandia Canyon

Depth (ft)[a]	443	443	464	495	495	810	805	805
Geologic Unit	CR basalt	CR basalt	CR basalt	old alluvium	old alluvium	SFG basalt[b]	SFG basalt	SFG basalt
Sample Treatment	Filtered	Nonfiltered	Filtered	Filtered	Nonfiltered	Filtered	Filtered	Nonfiltered
Date Sampled	04/13/98	04/13/98	04/29/98	04/30/98	04/30/98	06/02/98	06/08/98	06/08/98
Temp °C	14.2	14.2	15.5	16	16	18.9	18.9	18.9
Ag (ppm)	<0.001	<0.001	<0.001	<0.001	0.042	<0.001	<0.001	<0.001
Std. Dev. (+/-)					0.002			
Al (ppm)	<0.02	6.90	0.10	0.11	59.0	0.21	0.10	1.29
Std. Dev. (+/-)		0.01	0.01	0.01	0.7	0.01	0.01	0.03
Alk (laboratory) (ppm $CaCO_3$)	118	119	142	107	121	116	119	121
As (ppm)	0.0013	0.0021	0.0005	0.0005	0.015	0.0008	0.0019	0.0020
B (ppm)	0.069	0.079	0.16	0.088	0.19	0.04	0.06	0.06
Std. Dev. (+/-)	0.001	0.002	0.01	0.003	0.01	0.01	0.01	0.01
Ba (ppm)	0.015	0.057	0.036	0.014	0.58	0.079	0.085	0.094
Std. Dev. (+/-)	0.001	0.001	0.001	0.001	0.01	0.002	0.001	0.002
Be (ppm)	<0.002	<0.002	<0.002	<0.002	0.002	<0.002	<0.002	<0.002
Std. Dev. (+/-)					0.001			
Br (ppm)	0.18	0.23	0.23	0.17	0.19	0.05	0.08	0.08
Ca (ppm)	45.1	48.6	23.5	36.9	68.4	27.9	28.2	28.3
Std. Dev. (+/-)	0.1	0.2	0.1	0.1	0.2	0.2	0.2	0.1
Cd (ppm)	<0.001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001	<0.001
Std. Dev. (+/-)					0.001			
Cl (ppm)	31.5	32.0	197	33.4	35.7	9.52	10.1	9.93

Table 5.2-2 (continued)

Depth (ft)	443	443	464	495	495	810	805	805
Geologic Unit	CR basalt	CR basalt	CR basalt	old alluvium	old alluvium	SFG basalt	SFG basalt	SFG basalt
Sample Treatment	Filtered	Nonfiltered	Filtered	Filtered	Nonfiltered	Filtered	Filtered	Nonfiltered
Date Sampled	04/13/98	04/13/98	04/29/98	04/30/98	04/30/98	06/02/98	06/08/98	06/08/98
ClO_3 (ppm)	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Co (ppm)	<0.002	0.006	<0.002	<0.002	0.031	<0.002	<0.002	<0.002
Std. Dev. (+/-)		0.002			0.004			
CO_3 (ppm)	0	0	0	0	0	0	0	0
Conductivity (laboratory) (µS/cm)	429	433	1381	434	443	277	282	284
Cr (ppm)	<0.002	0.017	<0.002	<0.002	0.061	<0.002	0.006	0.008
Std. Dev. (+/-)		0.001			0.004		0.002	0.002
Cs (ppm)	<0.002	<0.002	<0.002	<0.002	0.008	<0.002	<0.002	<0.002
Std. Dev. (+/-)					0.002			
Cu (ppm)	0.007	0.040	0.007	0.003	0.22	0.004	0.006	0.007
Std. Dev. (+/-)	0.002	0.004	0.002	0.002	0.01	0.001	0.002	0.002
F (ppm)	0.52	0.53	0.85	0.28	0.29	0.47	0.43	0.43
Fe (ppm)	0.03	9.34	<0.01	0.12	95.8	0.12	<0.01	1.05
Std. Dev. (+/-)	0.01	0.01		0.01	0.7	0.01		0.01
Hardness ($CaCO_3$ ppm)	164	195	86.4	135	317	96.1	94.1	94.5
HCO_3 (ppm)	144	145	173	131	148	142	145	148
Hg (ppm)	<0.00005	<0.00005	0.00008	<0.00005	<0.00005	0.00014	<0.00005	0.00009
I (ppm)	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
K (ppm)	3.12	3.71	65.7	5.54	13.4	3.93	4.33	4.36
Std. Dev. (+/-)	0.01	0.01	0.3	0.01	0.01	0.01	0.02	0.02
Li (ppm)	0.09	0.09	0.08	0.05	0.09	0.04	0.04	0.04
Std. Dev. (+/-)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Mg (ppm)	12.4	17.9	6.72	10.4	35.5	6.42	5.76	5.80
Std. Dev. (+/-)	0.2	0.1	0.02	0.1	0.5	0.02	0.01	0.02
Mn (ppm)	0.026	0.18	0.12	0.083	2.01	0.065	0.029	0.042
Std. Dev. (+/-)	0.001	0.01	0.01	0.001	0.01	0.001	0.001	0.001
Mo (ppm)	0.005	0.013	0.066	0.007	0.007	0.022	0.003	0.003
Std. Dev. (+/-)	0.002	0.002	0.002	0.002	0.002	0.002	0.002	0.002
Na (ppm)	20.2	20.8	186	30.7	33.6	19.4	21.3	21.4
Std. Dev. (+/-)	0.2	0.1	2	0.1	0.1	0.1	0.1	0.1
NH_4 (ppm)	<0.02	<0.02	17.3	0.34	0.43	<0.02	0.02	0.02
Ni (ppm)	0.004	0.023	0.008	0.005	0.08	<0.002	0.002	0.004
Std. Dev. (+/-)	0.002	0.002	0.002	0.002	0.01		0.002	0.002

Table 5.2-2 (continued)

Depth (ft)	443	443	464	495	495	810	805	805
Geologic Unit	CR basalt	CR basalt	CR basalt	old alluvium	old alluvium	SFG basalt	SFG basalt	SFG basalt
Sample Treatment	Filtered	Nonfiltered	Filtered	Filtered	Nonfiltered	Filtered	Filtered	Nonfiltered
Date Sampled	04/13/98	04/13/98	04/29/98	04/30/98	04/30/98	06/02/98	06/08/98	06/08/98
NO_2 (ppm)	0.43	1.00	2.14	0.23	4.07	<0.02	0.18	<0.02
NO_3 (ppm)	21.7	21.2	1.04	24.2	13.0	4.48	2.03	2.12
Oxalate (ppm)	<0.02	<0.02	<0.02	0.39	<0.02	<0.02	<0.02	<0.02
Pb (ppm)	<0.002	0.004	<0.002	<0.002	0.06	<0.002	<0.002	0.002
Std. Dev. (+/-)		0.002			0.01			0.002
pH (laboratory)	7.95	7.50	7.65	7.92	7.29	7.94	7.88	7.80
PO_4 (ppm)	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Rb (ppm)	0.006	0.012	0.025	0.009	0.071	0.007	0.007	0.010
Std. Dev. (+/-)	0.002	0.002	0.002	0.002	0.005	0.002	0.002	0.002
Sb (ppm)	0.0005	0.0009	0.0010	0.0003	0.0011	0.0002	0.0002	0.0002
Se (ppm)	<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.0001	<0.0001	<0.0001
Si (ppm)	20.0	30.6	3.45	17.2	79.5	28.4	29.8	31.8
Std. Dev. (+/-)	0.1	0.2	0.01	0.1	0.9	0.1	0.1	0.1
SiO_2 (ppm calc)	42.8	65.5	7.38	36.8	170	60.8	63.8	68.1
SO_4 (ppm)	24.7	25.5	191	30.0	28.3	8.01	10.1	9.93
S_2O_3 (ppm)	<0.05	<0.05	<0.01	<0.05	<0.05	<0.01	<0.01	<0.01
Sn (ppm)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Sr (ppm)	0.18	0.24	0.44	0.19	0.55	0.15	0.16	0.17
Std. Dev. (+/-)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Ti (ppm)	<0.002	0.53	<0.002	<0.002	1.67	0.005	<0.002	0.015
Std. Dev. (+/-)		0.01			0.01	0.002		0.001
Tl (ppm)	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002
V (ppm)	0.003	0.013	<0.002	<0.002	0.095	0.005	0.012	0.012
Std. Dev. (+/-)	0.001	0.001			0.001	0.001	0.001	0.002
Zn (ppm)	0.06	0.60	<0.01	<0.01	0.65	<0.01	0.01	0.02
Std. Dev. (+/-)	0.01	0.01			0.01		0.01	0.01
TDS (ppm)	510.8	595.2	959.3	476.0	1029.2	379.8	386.0	395.8
Cation Sum	4.249	6.208	12.486	4.225	19.976	2.907	2.942	3.145
Anion Sum	4.154	4.206	12.472	4.129	4.343	2.862	2.935	2.973
Balance (%)	2.2700	n/a[c]	0.1100	2.3100	n/a	1.5400	0.2400	n/a

Note: The data in this table should be used only for screening purposes; empty cells indicate that the standard deviation is not calculated when the analysis is below detection limit.

[a] Sample collected at 810 ft is from undeveloped well; sample collected from 805 ft is from developed well.

[b] SFG basalt = Santa Fe Group basalt.

[c] n/a = Not applicable.

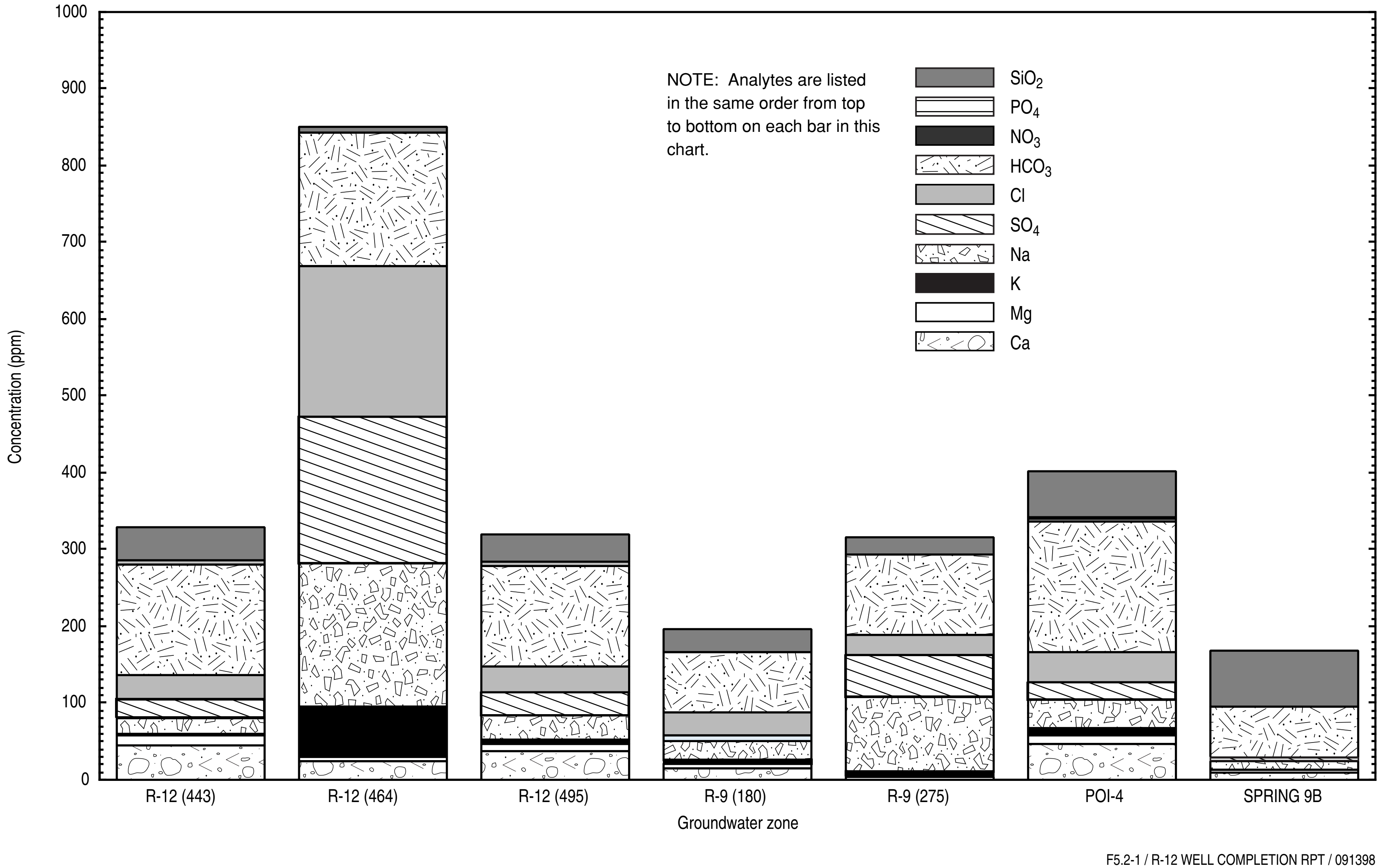


Figure 5.2-1. Comparison of major ion and nutrient chemistry of groundwater in R-12 with intermediate-depth perched groundwater in basalt (R-9, POI-4, and Spring 9B). Values in parentheses are sample depths in feet.

The uppermost sample collected from the perched zone, in Cerros del Rio basalt at a depth of 443 ft, is characterized by a mixed calcium-sodium-bicarbonate-chloride ionic composition with a field pH value of 7.65 and a total dissolved solids (TDS) of 511 ppm (filtered) (Figure 5.2-1; Tables 5.2-1 and 5.2-2). A groundwater sample collected from a depth of 464 ft in Cerros del Rio basalt is characterized by a sodium-calcium-chloride-sulfate-bicarbonate ionic composition with a field pH value of 7.65 and a TDS of 959 ppm (filtered) (Figure 5.2-1; Tables 5.2-1 and 5.2-2). Dissolved sodium, sulfate, and chloride concentrations in this sample are 186, 191, 197 ppm, respectively. The groundwater sample collected in the old alluvium at a depth of 495 ft is characterized by a calcium-sodium-bicarbonate-chloride ionic composition with a field pH value of 8.25 (Figure 5.2-1; Tables 5.2-1 and 5.2-2) and a TDS of 476 ppm (filtered). The chemistry of this water sample is similar to that of the sample collected at a depth of 443 ft.

The static water level is the same for all parts of the perched zone in R-12, suggesting that all saturated parts of this zone are hydraulically connected (see Section 4.1 of this document). However, water chemistries of samples collected at depths of 443 and 495 ft are distinct from those of the sample collected at 464 ft. These observations are difficult to reconcile for a hydraulically connected perched water zone. The sample at a depth of 464 ft may represent groundwater with a relatively long residence time compared with that of samples collected at depths of 443 and 495 ft. Though hydraulically connected, these groundwaters may acquire different chemical characteristics as they pass through the perched zone at different rates.

Stable isotope data for hydrogen and oxygen were collected to evaluate the sources of water encountered in R-12. The isotopic values for deuterium/hydrogen and oxygen-18/oxygen-16 in R-12 groundwater samples collected from depths of 443, 495, and 805 ft are -76 and -10.6 per mil, -77 and -11.0 per mil, and -72 and -10.8 per mil, respectively. These values plot close to the Jemez Mountain meteoric and global meteoric water lines provided by Blake et al. (1995, 49931), suggesting that these groundwaters were derived from a meteoric or atmospheric source, and that evaporation has not affected their isotopic composition.

Water quality data for Spring 9B in White Rock Canyon is provided in Figure 5.2-1 as a point of reference for evaluating the water quality data collected from perched groundwater in R-12. Spring 9B, which has a calcium-sodium-bicarbonate ionic composition, is the only known spring on the Pajarito Plateau discharging from basalt that does not contain elevated concentrations or activities of anthropogenic chemicals including chloride, nitrate, sulfate, tritium, and uranium. Perched groundwater in R-12 and Spring 9B do not have similar major ion compositions (Figure 5.2-1). In addition, concentrations of chloride, nitrate, and sulfate are higher in the R-12 perched groundwater in comparison with Spring 9B. Concentration of nitrate (as nitrogen) is typically 0.5 ppm in Spring 9B, whereas concentrations of this solute in the upper, middle, and lower portion of the perched zone in R-12 are 4.9, 0.21, 5.5 ppm, respectively (Table 5.2-2).

The major ion chemistries of the three samples collected from the perched zone in R-12 differ significantly from the chemistries of the two perched zones encountered in the Cerros del Rio basalt in R-9 (Figure 5.2-1). This suggests that groundwater within the basalt beneath Los Alamos Canyon at R-9 is not the same as that at R-12. This assumes that mineral precipitation/dissolution is not taking place along this inferred flow path, which could affect the major ion chemistry. Additional data interpretation, including geochemical modeling, will be performed in the future to assess water/rock interactions along groundwater flow paths within Sandia Canyon and possibly Mortandad Canyon.

The perched groundwater zone within the Cerros del Rio basalt and old alluvium at R-12 may contain a component of surface water and alluvial groundwater derived from upper Sandia Canyon to the west. Historic information suggests that discharge of treated sewage effluent from TA-3 in upper Sandia Canyon contained tritium (Rogers 1998, 59169). Current releases of treated effluent contain detectable concentrations of ammonium, nitrate, and organic nitrogen; organic nitrogen also was found in alluvial groundwater within Mortandad Canyon (Kendrick 1999, 66141). Surface water samples collected east of the TA-3 outfall show that this treated effluent is characterized by a sodium-bicarbonate-chloride ionic composition with an alkaline pH (Environmental Surveillance and Compliance Programs 1997, 56684). However, the major ion chemistry of treated effluent from TA-3 (sodium-bicarbonate-chloride) differs from that of the perched zone (calcium-sodium-bicarbonate) at R-12, based on recent analytical data (Environmental Surveillance and Compliance Programs 1997, 56684). Thus, the relationship between TA-3 effluent and perched water at R-12, if any, is poorly understood.

Another potential source of groundwater contributing to the chemical composition of perched groundwater observed at R-12 may be Mortandad Canyon. Alluvial groundwater in Mortandad Canyon contains activities of tritium, fission products, and actinides and concentrations of nitrate, sodium, calcium, bicarbonate, and other major ions above background values (LANL 1997, 56835). If perched groundwater originating in Mortandad Canyon flows east toward Sandia Canyon, it is possible that this groundwater mixes with perched groundwater beneath Sandia Canyon. This mixed groundwater could influence the water chemistry observed at R-12.

The perched groundwater in the Cerros del Rio basalt and old alluvium encountered in R-12 are chemically similar to those found in a similar geologic setting in well POI-4 located approximately 1.2 km to the north in lower Pueblo Canyon (Figure 5.2-1). This suggests that the occurrence of perched groundwater in basalts found in Pueblo Canyon and Sandia Canyon may have been affected by similar contaminant source chemistries of recharge water (treated sewage effluent from the TA-3 in Sandia Canyon and the sewage treatment plants in Pueblo Canyon). However, these two canyons are probably not hydraulically connected between POI-4 and R-12. Perched intermediate groundwater beneath Pueblo Canyon probably flows east-southeast and partially discharges at Basalt Spring, whereas perched groundwater beneath Sandia Canyon probably flows east-southeast, possibly discharging at Sandia Spring west of the Rio Grande.

5.2.2.2 Quality of Groundwater Within the Santa Fe Group Basalt

The regional saturated zone at R-12 occurs in Santa Fe Group basalt at a depth of 805 ft and is characterized by a calcium-sodium-bicarbonate ionic composition with a TDS content of 386 ppm (Figure 5.2-2; Table 5.2-2). The major cation and anion chemistry of this water is similar to that of regional aquifer water in R-9 and in supply wells PM-1 and PM-3 (Figure 5.2.2). Also the major cation and anion chemistry of the regional aquifer in R-12 is similar to that of the upper and lower portions of the perched zone (443 and 495 ft), but lower concentrations of calcium, chloride, and sulfate are present in the regional aquifer. Concentrations of chloride and sulfate at the top of the regional aquifer in R-12 are 10.1 ppm and 10.1 ppm, respectively. Concentrations of these two solutes are slightly greater than those found in PM-1 (chloride = 6.6 mg/L, sulfate = 6.1 mg/L) and PM-3 (chloride = 7 mg/L, sulfate = 6.3 mg/L) (Environmental Surveillance and Compliance Programs 1997, 56684). Concentrations of nitrate (as nitrogen) less than 1 ppm or mg/L are similar in R-12, PM-1, and PM-3.

5.2.2.3 Radionuclide Distributions in Groundwater

Activities of total and dissolved radionuclides (americium-241; cesium-137; plutonium-238; plutonium-239,240; strontium-90; and tritium); gross alpha; gross beta; and gross gamma in groundwater samples collected at R-12 are summarized in Tables 5.2-3 and 5.2-4, respectively. Activities of gross alpha, gross beta, and gross gamma are greater than 1 pCi/L for both filtered and nonfiltered samples. Activities of most radionuclides (excluding plutonium-239,240; tritium; and uranium) are less than detectable levels in both saturated zones.

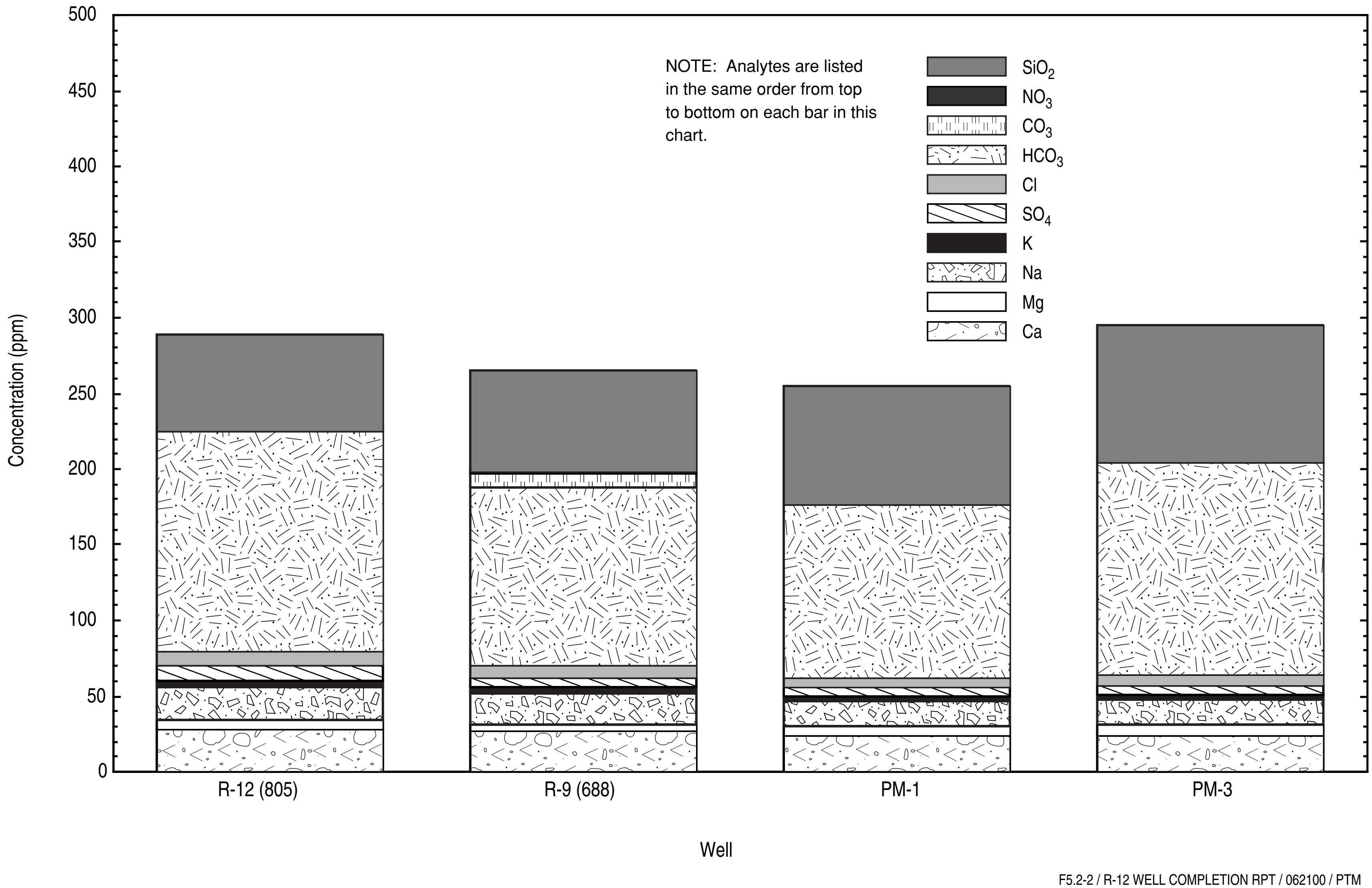


Figure 5.2-2. Comparison of major ion and nutrient chemistry of Santa Fe Group groundwater in R-12 with regional aquifer groundwater in nearby supply wells PM-1 and PM-3. Values in parentheses are sample depths in feet.

Table 5.2-3
Radionuclide Activities in Samples of Nonfiltered Groundwater from Borehole R-12

Depth (ft)	443	464	495	805
Geologic Unit	CR basalt[a]	CR basalt[b]	CR basalt	SFG basalt[c]
Tritium	254.7 ± 16.6	208.1 ± 7.0	249.3 ± 8.3	46.9 ± 1.6
Strontium-90	0.47 ± 0.75	-0.20 ± 0.32	-0.04 ± 0.71	0.16 ± 0.66
Cesium-137	-0.793 ± 1.95	0.040 ± 0.074	-0.3 ± 2.0	-1.3 ± 1.9
Plutonium-238	-0.0145 ± 0.0170	0.0111 ± 0.0156	-0.011 ± 0.010	-0.0024 ± 0.0174
MDA[d]	0.063	0.27	0.068	0.047
Plutonium-239, 240	0.023 ± 0.026	0.048 ± 0.028	0.0066 ± 0.0089	0.0015 ± 0.0174
MDA	0.047	0.024	0.032	0.0138
Americium-241	0.0168 ± 0.0192	0.014 ± 0.022	0 .0152 ± 0.0194	0.0127 ± 0.0170
MDA	0.017	0.021	0.034	0.029
Uranium-234	1.74 ± 0.26	2.13 ± 0.32	2.56 ± 0.38	2.39 ± 0.36
MDA	0.03	0.036	0.038	0.038
Uranium-235	0.061 ± 0.034	0.146 ± 0.052	0.085 ± 0.048	0.070 ± 0.042
MDA	0.027	0.036	0.057	0.043
Uranium-238	0.926 ± 0.176	2.46 ± 0.34	1.15 ± 0.20	1.32 ± 0.22
MDA	0.027	0.032	0.032	0.047
Uranium (LIKPA[e]) (µg/L)	2.56 ± 0.35	7.5 ± 1.0	10.2 ± 1.4	4.26 ± 0.58
MDC[f]	0.10	0.49	1.00	0.10
Gross Alpha	2.2 ± 1.3	23.6 ± 9.4	24.4 ± 4.1	5.52 ± 0.92
Gross Beta	4.9 ± 1.5	15.2 ± 5.6	27.2 ± 4.0	6.0 ± 1.0
Gross Gamma	111 ± 13	11.09 ± 1.88	226 ± 18	213 ± 17
MDA	17	0.55	18	18

Note: pCi/L.
[a] CR basalt = Cerros del Rio basalt.
[b] Sediment with water from sample with high suspended solids content, pCi/g, excluding tritium and uranium.
[c] SFG basalt = Santa Fe Group basalt.
[d] MDA = minimum detectable activity.
[e] LIKPA = laser-induced kinetic phosphorimetric analysis.
[f] MDC = minimal detectable concentration.

The activities of tritium for the groundwater samples collected at depths of 443, 464, and 495 ft in R-12 are 254.7 ± 16.6 (two standard deviations), 208.1 ± 7.0, and 249.3 ± 8.3 pCi/L, respectively (Table 5.2-3). The tritium activity for the regional aquifer at R-12 is 46.9 ± 1.6 pCi/L. Groundwater in both saturated zones contains a component of surface water and/or alluvial water that is less than 50 years old (Blake et al. 1995, 49931; Adams et al. 1995, 47192) based on these elevated tritium activities.

Table 5.2-4
Radionuclide Activities in Samples of Filtered Groundwater from Borehole R-12

Depth (ft)[a]	443	464	495	805
Geologic Unit	CR basalt[b]	CR basalt	CR basalt	SFG basalt[c]
Tritium[d]	(see non filtered data for results of tritium analyses for the four saturated zones)			
Strontium-90	-0.52 ± 0.82	-0.20 ± 0.70	0.04 ± 0.71	-0.31 ± 0.60
Cesium-137	-0.516 ± 2.14	0.1 ± 2.0	0.2 ± 2.0	0.4 ± 2.1
Plutonium-238	-0.007 ± 0.030	0.010 ± 0.030	0.001 ± 0.011	0.0006 ± 0.0196
MDA[e]	0.079	0.075	0.059	0.054
Plutonium-239, 240	0.011 ± 0.026	0.016 ± 0.030	-0.0004 ± 0.0086	0.082 ± 0.016
MDA	0.059	0.058	0.032	0.029
Americium-241	-0.52 ± 0.82	0.032 ± 0.034	0.008 ± 0.022	0.034 ± 0.036
MDA	0.053	0.060	0.050	0.062
Uranium-234	1.53 ± 0.24	2.93 ± 0.42	2.17 ± 0.34	2.08 ± 0.32
MDA	0.046	0.053	0.055	0.044
Uranium-235	0.052 ± 0.032	0.134 ± 0.058	0.039 ± 0.032	0.143 ± 0.058
MDA	0.036	0.049	0.044	0.044
Uranium-238	0.962 ± 0.172	0.703 ± 0.158	0.948 ± 0.182	1.42 ± 0.24
MDA	0.061	0.033	0.048	0.030
Uranium (LIKPA[f]**) (μg/L)**	2.51 ± 0.34	2.04 ± 0.28	2.46 ± 0.34	4.08 ± 0.56
MDC[g]	0.10	0.10	0.10	0.10
Gross Alpha	2.0 ± 1.1	insufficient sample	2.75 ± 0.63	2.55 ± 0.74
Gross Beta	4.0 ± 1.4	insufficient sample	4.48 ± 0.89	4.50 ± 0.94
Gross Gamma	135 ± 14	232 ± 18	225 ± 18	210 ± 17
MDA	19	18	17	18

Notes: 1. pCi/L.
2. Error of 2 standard deviations is reported.

[a] Zones 443 ft, 464 ft, 495 ft, and 805 ft were sampled on 04/13/98, 04/29/98, 04/30/98, and 06/08/98, respectively.

[b] CR basalt = Cerros del Rio basalt.

[c] SFG basalt = Santa Fe Group basalt.

[d] Tritium analyzed by University of Miami; other radionuclides and parameters analyzed by Paragon Analytics, Inc.

[e] MDA = minimum detectable activity (pCi/L).

[f] LIKPA = laser-induced kinetic phosphorimetric analysis.

[g] MDC = minimal detectable concentration (μg/L).

The combined isotopes plutonium-239,240 are detected (0.048 ± 0.028 pCi/g, MDA = 0.024 pCi/g) in a mixture of water and sediment separated from the sample with a high suspended solids content collected from a depth of 464 ft (Table 5.2-3). Plutonium-239,240 was not detected in a filtered split of the same water sample. Plutonium-239,240 was detected (0.082 ± 0.016 pCi/L, MDA = 0.029 pCi/L) in a filtered groundwater sample collected from 805 ft (Table 5.2-4). However, plutonium-230,240 was not detected in a nonfiltered split of the same sample (Table 5.2-3). Resampling plutonium-239,240 and other radionuclides is recommended during quarterly sampling at R-12.

Dissolved uranium concentrations in groundwater samples collected at 443, 464, and 495 ft are 2.51, 2.04, and 2.46 µg/L, respectively. The dissolved uranium concentration in the sample collected at 805 ft is 4.08 µg/L. Concentrations of dissolved uranium in perched groundwater and the regional aquifer at R-12 are below the proposed EPA maximum concentration level (MCL) of 20 µg/L and the New Mexico Water Quality Control Commission standard of 5 mg/L. However, background concentrations of dissolved uranium in the upper portion of the regional saturated zone, west of the Rio Grande, typically are less than 2 µg/L (see Table 5.2-6 in Broxton et al. 2000, 66599; Environmental Surveillance and Compliance Programs 1997, 56684). Further work is needed to determine if uranium concentrations and their isotopic ratios in groundwater of the regional aquifer are within the range of natural background values.

Under oxidizing conditions, uranium is predicted to occur as $UO_2(CO_3)_2^{-2}$ and $UO_2(CO_3)_3^{-4}$ within the upper and lower portion of the perched zone, based on model simulations using the computer code MINTEQA2 (Allison et al. 1991, 49930). These uranyl carbonate complexes do not completely adsorb onto ferric oxyhydroxide surfaces at pH values greater than 7.5 in the presence of carbon dioxide gas at 10^{-2} atmosphere (Langmuir 1997, 56037). This desorption process probably accounts for elevated concentrations of uranium in the perched zone.

Total (dissolved and suspended) uranium concentrations in the upper, middle, and lower portions of the perched zone are 2.56, 7.5, and 10.2 µg/L, respectively. Turbidity values for the middle and lower portion of the perched zone exceeded the maximum readable value for the instrument, suggesting that high particulate contents account for a significant portion of the uranium in the nonfiltered samples.

5.2.2.4 Nitrogen Isotopes in Groundwater

The main sources of nitrate found in groundwater and surface water at the Laboratory include (1) natural organic nitrogen in soils, (2) dissolved nitric acid discharges, (3) fertilizers, and (4) treated septic/effluent discharges. Of these possible sources, aqueous discharges of both dissociated nitric acid and treated septic/effluent probably exceed naturally and fertilizer-derived nitrate.

Water samples were collected from R-12 and from several other wells, springs, and treated outfalls within Los Alamos Canyon, Pueblo Canyon, and Sandia Canyon and at TA-50 and were analyzed for ammonium, nitrate, and nitrogen-15/nitrogen-14. Analytical results of nitrogen species and isotopes are presented in Table 5.2-5.

The isotopic standard for nitrogen-15/nitrogen-14 is nitrogen in air, which has a nitrogen-15/nitrogen-14 value of zero (Clark and Fritz 1997, 59168). Nitrate derived from treated septic effluent is enriched in nitrogen-15 and depleted in nitrogen-14 and is characterized by positive nitrogen-15/nitrogen-14 ratios (7 to >30 per mil; Clark and Fritz 1997, 59168). During denitrification, which is the reduction of nitrate to nitrogen gas in the presence of organic carbon, residual nitrate becomes enriched in nitrogen-15. Subsequently, nitrogen-15/nitrogen-14 ratios become increasingly more positive with increasing denitrification.

Groundwater samples collected from R-12 (at 443, 464, 495, and 805 ft), Basalt Spring, the TA-3 outfall, TW-1A, and TW-1 have nitrogen-15/nitrogen-14 values ranging from 11.3 to 34.2 per mil (Table 5.2-5). Possible sources of nitrate in these waters, based on their nitrogen isotopic analyses, is septic/effluent derived from sewage treatment plants. This is consistent with known sources of treated effluent discharge from the sewage treatment plants in Pueblo Canyon and the TA-3 discharge in upper Sandia Canyon.

Table 5.2-5
Summary of Nitrogen Chemistry and Nitrogen Isotopes for Several Waters in Sandia, Pueblo, Los Alamos Canyon, and TA-50

Location	NO_3-N	NH_4-N	Del $^{15/14}N$-NO_3	Del $^{15/14}N$-NH_4	Water Type
R-12 (443 ft)	4.9	<0.02	15.2 (3)		Perched
R-12 (464 ft)	0.21	13.5	21.3 (2)	1.3 (2)	Perched
R-12 (495 ft)	5.5	0.26	20.3 (2)		Perched
R-12 (805 ft)	0.46	0.02	11.3 (2)		Regional
R-9 (579 ft)	2.4	0.07	3.0 (2)		Regional
Stream below Bayo Sewage Treatment Plant in Pueblo Canyon			7.8 (2)		Effluent
TW-1A	<0.02	0.29	24.6 (2)		Perched
TW-1	5.3	0.04	17.2 (3)		Regional
Basalt Spring	4.5	0.02	34.2 (2)		Perched
LA Spring	2.8	<0.02	2.8 (2)		Perched
TA-50	67.3	4.73	2.1 (2)		Effluent
TA-3	1.5	0.12	32.4 (2)		Effluent
HNO_3 Std.*	5.7	<0.02	1.0 (4)		Acid

Notes: 1. Concentrations of nitrate and ammonium in units of ppm; isotopes in units per mil or parts per thousand.

2. Nitrogen isotopic analyses performed by Coastal Science Laboratories, Inc., Austin, Texas. The number of isotopic analyses for each sample are given in parentheses.

* Laboratory HNO_3 standard prepared at EES-1.

Nitric acid is produced by reacting ammonia gas with oxygen gas. Ammonia is oxidized to nitrate through a series of reactions involving nitrous oxide, nitric oxide, and nitric dioxide, which eventually produces nitric acid. Ammonia is initially produced by reacting nitrogen gas, having a nitrogen-15/nitrogen-14 ratio of zero per mil, with hydrogen gas. Consequently, the nitrogen-15/nitrogen-14 value for nitric acid is close to zero or is slightly enriched with nitrogen-15. A nitric acid standard prepared by EES-1 personnel has an average nitrogen-15/nitrogen-14 value of 1.0 per mil (Table 5.2-5). The treated effluent sampled at TA-50 contains elevated nitrate concentrations and low nitrogen-15/nitrogen-14 (Table 5.2-5) dominantly derived from nitric acid associated with the TA-55 waste stream.

Organic nitrogen derived from soils is enriched in nitrogen-15 and depleted in nitrogen-14. Accordingly, soils containing organic nitrogen are characterized by positive nitrogen-15/nitrogen-14 ratios that typically range from 3 to 7 per mil (Clark and Fritz 1997, 59168). Samples collected from R-9 (at 579 ft), R-12 (at 805 ft) and Los Alamos Spring have nitrogen-15/nitrogen-14 ratios consistent with those of nitric acid and perhaps soil organic nitrogen (Table 5.2-5).

Ammonium was detected in R-12 groundwater at a depth of 464 ft. Ammonium is the thermodynamically stable form of nitrogen under reducing conditions. The nitrogen-15/nitrogen-14 ratio for ammonium in this groundwater sample is 1.3 per mil, which implies a different source (abiological) of ammonium than that found in the samples at depths of 443 and 495 ft. The ammonium may be naturally derived from clay minerals through cation exchange or possibly from an industrial source such as laboratory cleaners containing ammonium. More work is required to understand the sources of ammonium at the depth of 464 ft in R-12.

5.2.2.5 Summary of Groundwater Chemistry

Solute chemical data show the presence of possible elevated concentrations of some anions (chloride, nitrate, and sulfate) within the four groundwater samples collected during the drilling of R-12. These solutes are probably derived from alluvial groundwater in upper Sandia Canyon. Nitrate concentrations observed in R-12 groundwater at depths of 443 and 495 ft are above background values, which are typically less than 0.5 ppm nitrate as nitrogen. In addition, nitrogen isotopic data for these two samples is consistent with derivation of nitrate from a sewage source, possibly the TA-3 outfall.

Measurable activities of tritium within the two saturated zones at R-12 suggest that a component of groundwater in these zones is less than 50 years old, and is derived from atmospheric fallout (Adams et al. 1995, 47192) and/or from Laboratory discharges (Blake et al. 1995, 49931). Activities of cesium-137; strontium-90; plutonium-238; plutonium-239,240; and americium-241 are generally less than detection in groundwater samples collected from R-12.

A dissolved uranium concentration of 4.08 µg/L was measured in a sample of regional aquifer groundwater collected within the basalt of the Santa Fe Group. This value is possibly a statistical outlier with respect to uranium concentrations for 65 groundwater and spring samples (mean value of 1.86 µg/L) collected on the Pajarito Plateau and surrounding areas.

5.3 Anion Profiles

5.3.1 Methods

Anion profiles (bromide, chloride, nitrate, nitrite, phosphate, oxalate, and sulfate) were determined from core and cutting samples from borehole R-12. Samples were collected and analyzed at approximately 10-ft intervals. A few samples were taken on more closely spaced intervals to examine behavior at stratigraphic contacts or changes in moisture content. Anion concentrations were determined by leaching the core samples with deionized water and analyzing the leachate using ion chromatography following Newman (1996, 59118). The leaching and analyses were performed at the Los Alamos EES-1 geochemistry laboratory. For each sample, approximately 50 g of tuff was crushed using a mortar and pestle. The tuff was then oven-dried for at least 12 hr at 100°C. The dry sample was weighed and added to an Erlenmeyer flask along with approximately 75 g of deionized water. The flask was agitated for 24 hr on a rotary mixer. Once the mixer was turned off and the solid material settled, the supernatant was filtered and analyzed using a Dionex ion chromatograph. Analytical precision of the ion chromatograph is better than 5%.

Pore water chloride concentrations were calculated using leachate concentrations, gravimetric moisture contents, and bulk densities. Moisture content data are reported in Section 5.4. Bulk densities have not been measured on the R-12 samples, so estimates were used that were representative of typical values for the kinds of rock and sediments encountered. The bulk density estimates increase the uncertainty in the pore water concentrations. However, comparisons of calculated pore water chloride concentrations from saturated zone samples to those reported in Section 5.2.2.1 show reasonable agreement, indicating that the bulk density estimates are close to the actual values.

5.3.2 Anion Profile Results

Analysis of the vertical variations in geochemistry of Sandia Canyon is a helpful way of understanding flow and transport in the subsurface. One important component of the subsurface geochemistry is the distribution of anions. Core and cutting samples obtained from the R-12 borehole were analyzed to obtain the vertical distributions of bromide, chloride, nitrate, nitrite, phosphate, oxalate, and sulfate (Table 5.3-1).

Several samples had bromide, nitrate, nitrite, and phosphate concentrations below the detection limit. The lack of detection does not mean that these species are not present in the samples. Instead, the leaching procedure results in substantial dilution, and if an anion has a low concentration, the dilution can lower the concentration beyond the detection limit. Cuttings and core-based chloride pore water values for samples in and near the saturated zones are similar to analyses of the water samples collected directly from the saturated zones (Section 5.2.2.1). However, some of the sulfate concentrations are higher than those for the direct water sample analyses, possibly reflecting desorption of additional sulfate from the rock.

Table 5.3-1
Estimates of R-12 Anion Pore Water Concentration

Depth (ft)	Bromide	Chloride	Nitrate	Nitrite	Oxalate	Phosphate	Sulfate
5	3	260	BD	BD	BD	89	662
10	2	261	BD	BD	BD	85	542
15	1	81	BD	BD	BD	29	131
20	2	47	BD	BD	BD	35	56
25	1	100	BD	BD	BD	41	221
30	BD*	70	BD	BD	BD	26	139
40	BD	18	BD	BD	BD	BD	73
49	BD	7	BD	BD	BD	4	11
60	BD	11	BD	BD	BD	2	18
70	1	29	BD	BD	38	2	112
80	BD	10	BD	BD	BD	BD	16
90	BD	10	BD	BD	BD	1	11
100	BD	13	BD	BD	0.4	BD	23
110	BD	12	BD	BD	BD	BD	14
120	BD	36	3	BD	BD	BD	19
130	BD	41	16	BD	BD	BD	12
131	BD	8	6	BD	BD	BD	8
140	BD	7	BD	BD	BD	9	75
151	BD	6	BD	BD	10	BD	68
171	BD	67	BD	BD	141	70	265
181	BD	168	BD	BD	BD	65	130
201	BD	8	BD	BD	36	BD	44
220	BD	11	BD	BD	BD	44	74
228	BD	14	BD	BD	BD	BD	77
237	BD	12	BD	BD	5	15.4	65
249	BD	33	BD	BD	26	51	154
262	BD	2	4	BD	BD	BD	5
270	BD	7	BD	BD	BD	6	35
279	BD	30	BD	BD	BD	23	116
289	BD	5	BD	BD	BD	6	29

Table 5.3-1 (continued)

Depth (ft)	Bromide	Chloride	Nitrate	Nitrite	Oxalate	Phosphate	Sulfate
300	BD	13	BD	BD	BD	3	31
309	BD	78	BD	BD	BD	10	78
319	2	95	3	BD	BD	7	239
329	3	82	BD	BD	7	15	184
339	BD	43	BD	BD	19	2	97
343	BD	4	7	BD	BD	BD	15
349	BD	5	1	BD	BD	BD	13
352	BD	18	BD	BD	BD	BD	33
358	BD	116	BD	BD	BD	10	83
370	BD	64	BD	BD	BD	13	97
380	BD	40	BD	BD	BD	19	59
387	BD	34	BD	BD	BD	BD	59
396	BD	106	BD	BD	BD	BD	112
401	BD	65	BD	BD	13	BD	99
407	BD	3	4	BD	BD	BD	9
421	2	13	BD	BD	15	BD	52
421	2	13	BD	BD	10	BD	42
440	5	31	BD	BD	140	BD	177
443	BD	30	BD	BD	42	BD	108
459	BD	85	BD	BD	126	22	342
520	BD	1	1	BD	27	BD	735
560	BD	10	BD	BD	BD	BD	54
570	BD	19	BD	BD	52	BD	95
579	BD	82	BD	BD	BD	25	252
590	BD	4	BD	BD	BD	BD	27
600	BD	6	BD	BD	8	2	32
610	BD	5	BD	BD	11	BD	30
619	BD	4	BD	BD	9	BD	26
629	BD	2	BD	BD	9	BD	22
640	BD	10	BD	BD	21	BD	45
649	BD	8	BD	BD	9	BD	46
659	BD	9	BD	BD	10	BD	36
673	BD	4	BD	BD	10	BD	32
710	BD	6	BD	BD	BD	BD	10
720	BD	5	2	0.2	1	BD	3
730	BD	6	BD	BD	2	BD	4
742	BD	3	BD	BD	BD	BD	7
751	BD	6	BD	0.1	BD	BD	20
761	BD	5	BD	0.1	0.4	BD	23
771	BD	3	BD	0.2	0.4	BD	19

Table 5.3-1 (continued)

Depth (ft)	Bromide	Chloride	Nitrate	Nitrite	Oxalate	Phosphate	Sulfate
779	BD	6	BD	0.3	BD	BD	10
805	BD	9	BD	2.6	2	42	30
810	BD	12	BD	4.6	9	BD	67

Note: mg/L.

* BD = below detection.

In general, the anions showed similar behavior with multipeaked profiles, and the peaks and valleys of the various anion distributions tend to occur at similar depths (Figures 5.3-1 and 5.3-2). The high concentrations of bromide, chloride, phosphate, and sulfate above 20 ft may be related to enrichment resulting from evapotranspiration. These shallow concentrations are a typical result of root zone effects. Concentrations of anions are highly variable in the zone from the Otowi Member through the Cerros del Rio basalt. This variation may be related to the occurrence of buried soils, or to changes in moisture content and bulk density. The high sulfate concentration at 520 ft (at the bottom of the perched zone) is anomalous. Other anions have more dilute concentrations at this depth. It is not clear what the reason is for this enrichment in sulfate, but it could be related to a water/rock interaction effect. Except for a small increase (spike) in concentrations near the top of the Puye Formation, concentrations show much less variability than concentrations above the perched saturated zone. The Puye Formation anion concentrations are similar to those in borehole R-9, although R-9 has more variation with depth.

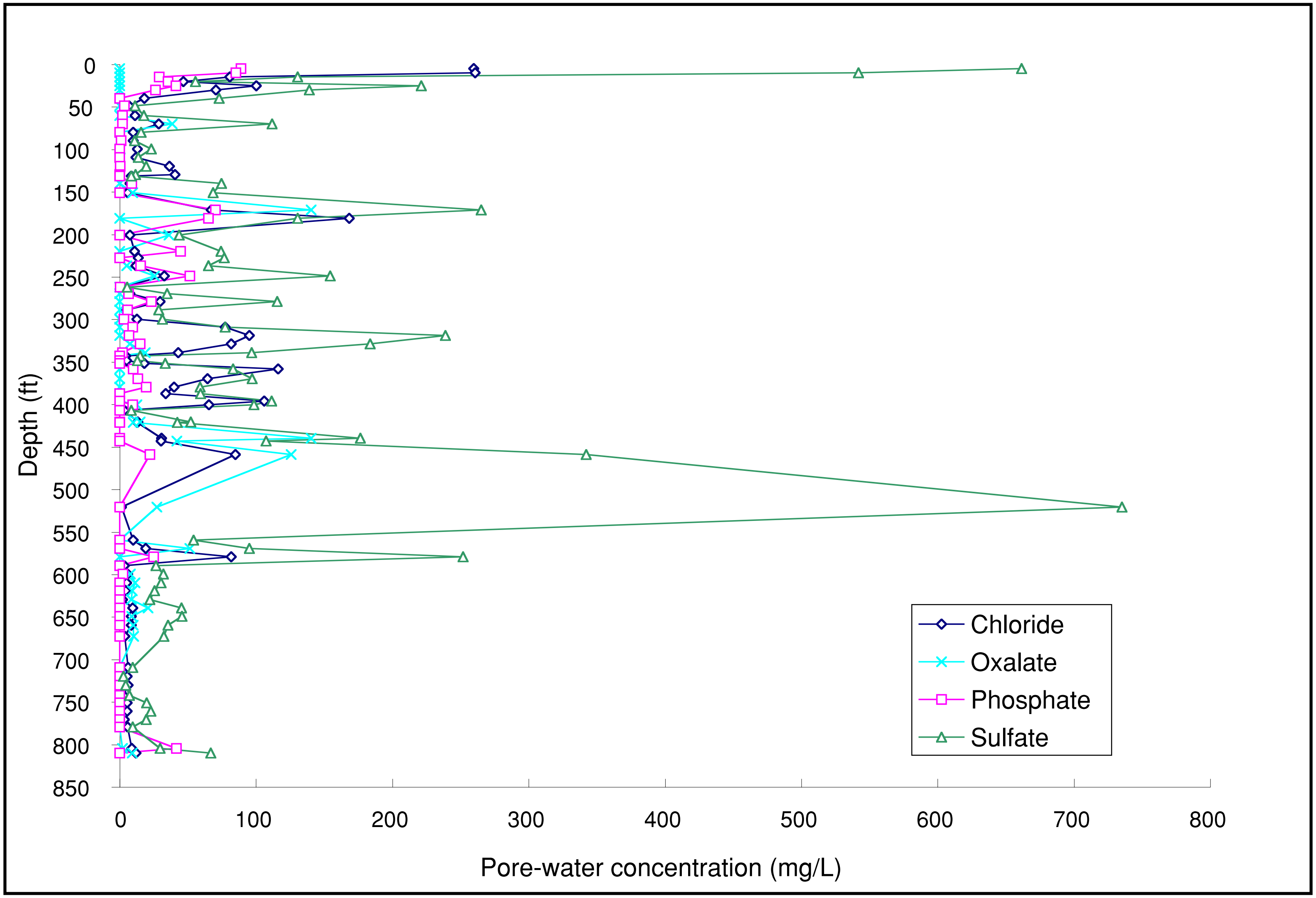
5.4 Moisture Content of Core and Cuttings

5.4.1 Methods

Moisture content was determined on samples of both core and cuttings. Core was collected from only 11.4% of the borehole, including all the saturated intervals. Therefore, collecting a vertical profile of moisture content for the entire borehole requires that analyses for moisture content be performed on drill cuttings. The drill cuttings were collected from a port that was installed in the cuttings return line at a location before the cuttings entered the cyclone. This was done to prevent the moisture loss that occurs when cuttings are in the cyclone. After core or cuttings were screened for radioactivity, samples were immediately placed in preweighed and prelabeled jars with tightly fitting lids. The moisture content was determined gravimetrically by drying the samples in an oven in accordance with the American Society for Testing and Materials (ASTM) method D2216-90. Samples collected for moisture content are listed with the analytical results in Appendix C.

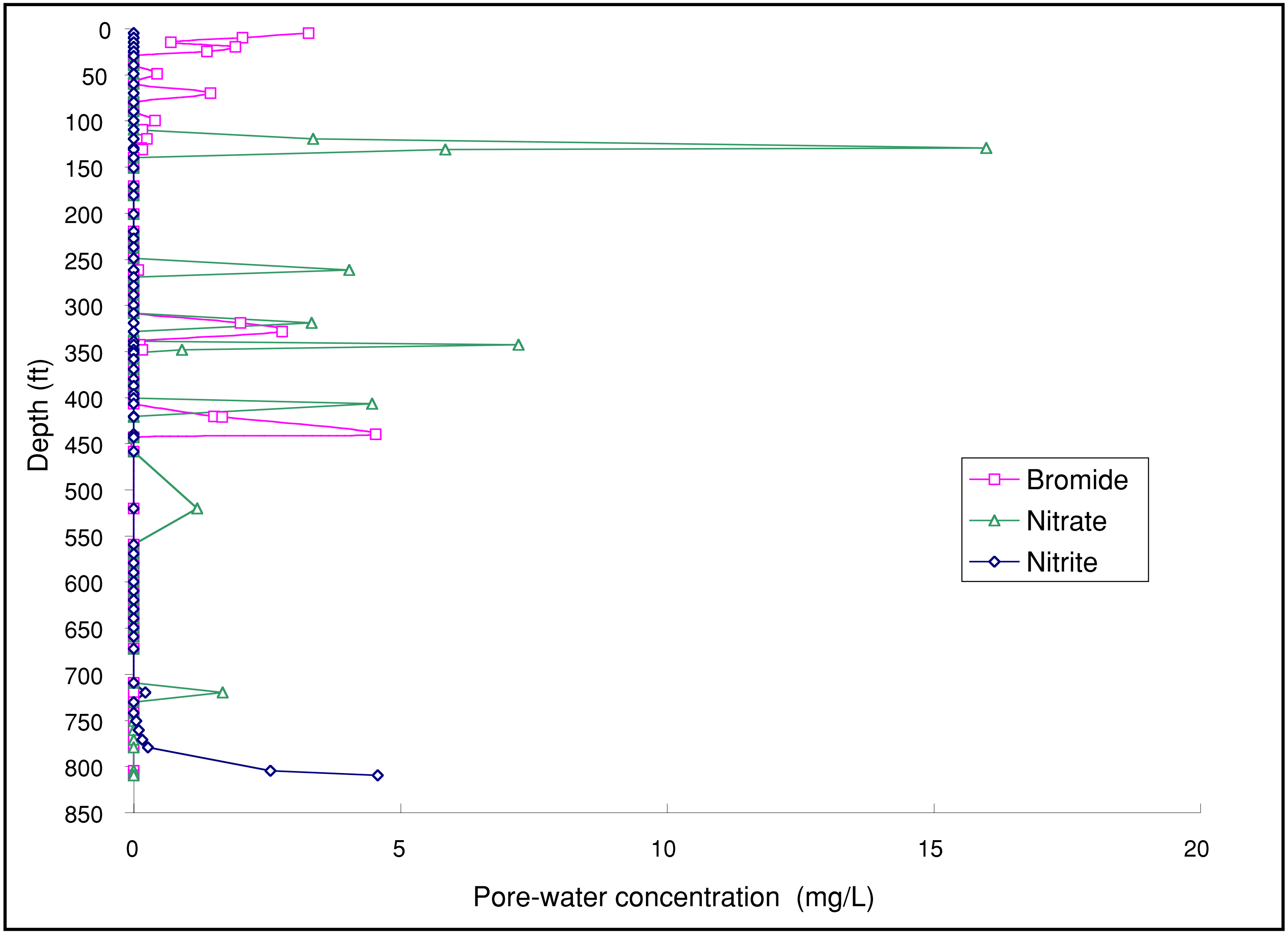
5.4.2 Results

Moisture contents systematically increase downsection from 2% to 6% within alluvium and Cerro Toledo deposits to 12% to 20% near the base of the ash-flow tuffs in the Otowi Member (Figure 5.4-1). Moisture contents range from 12% to 28% within the Guaje Pumice Bed and underlying soil. A similar pattern of downward increasing moisture was reported for core samples collected from the Otowi Member and Guaje Pumice Bed in LADP-3, approximately 4 km west-northwest of R-12 (Broxton et al. 1995, 50119). Moisture contents for the Otowi Member in LADP-3 range from 10% to 35% and are generally higher than those for R-12, possibly reflecting the wetter conditions beneath Los Alamos Canyon.



F5.3-1 / R-12 WELL COMPLETION RPT / 082400 / PTM

Figure 5.3-1. Pore-water chloride, oxalate, phosphate, and sulfate concentrations for borehole R-12



F5.3-2 / R-12 WELL COMPLETION RPT / 082400 / PTM

Figure 5.3-2. Pore-water bromide, nitrate, and nitrite concentrations for borehole R-12

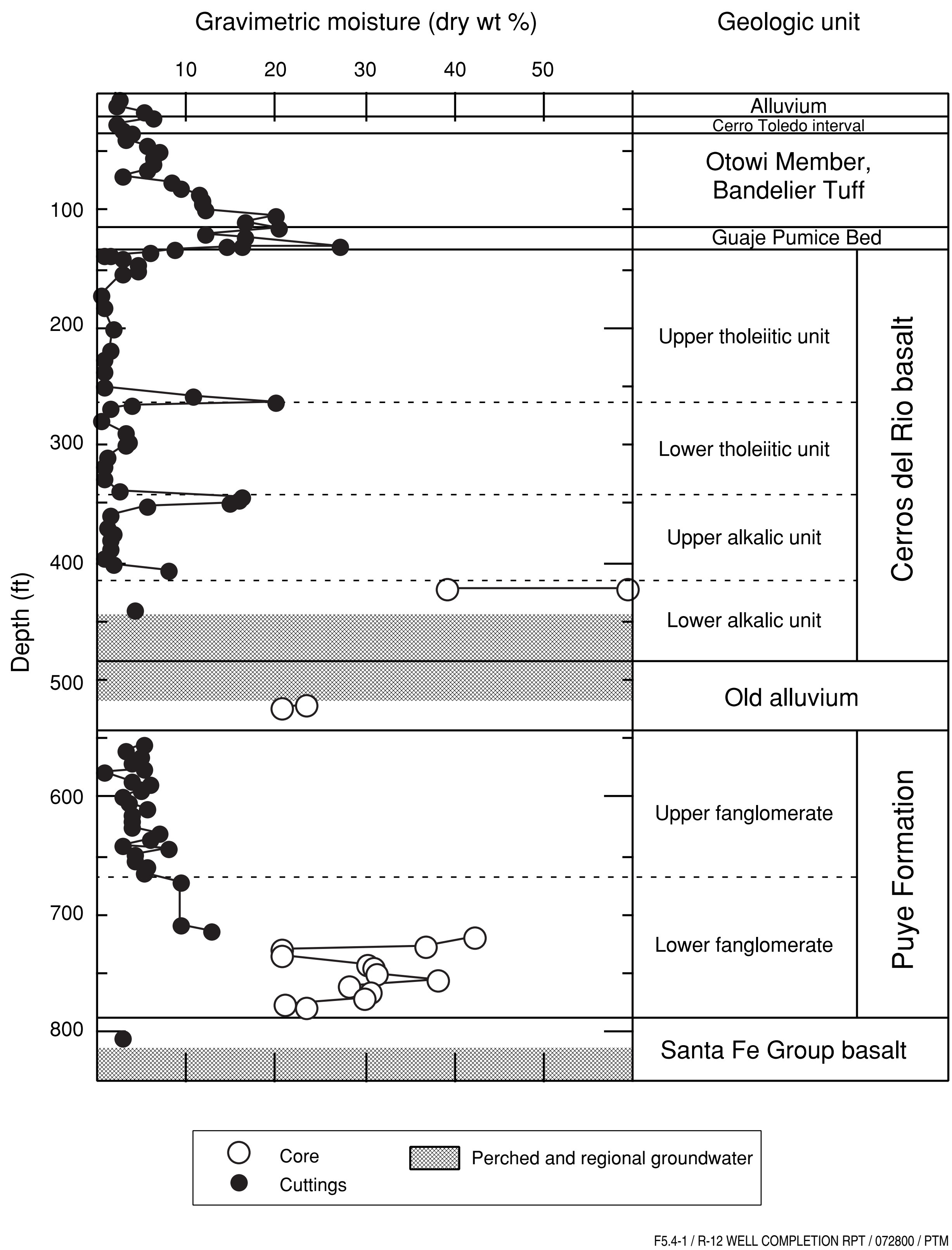


Figure 5.4-1. Moisture content of core and cuttings in R-12

Moisture contents are generally low, typically 1% to 3%, within basaltic rocks of the Cerros del Rio volcanic field. Moisture spikes at depths of 262 and 343 ft correlate with clay-rich, vesicular zones associated with basalt flow unit boundaries (Appendix A; Figure 5.4-1). High moisture contents (39% to 59%) were associated with the paleosol separating the upper alkalic flow from the lower alkalic flow.

Moisture contents increase downsection through the Puye Formation. Moisture contents for cuttings from the vitric, upper portion of the Puye Formation are typically 3% to 6%. Moisture contents for cuttings from the argillic, lower part of the Puye Formation range from 9% to 13%, but cores from near the base of the formation yielded markedly higher measurements, ranging from 20% to 42%. These patterns are similar to R-9 and might reflect increased alteration of the Puye Formation downsection.

5.5 Matric Potential

This section concerns the measurement of the water pressure potential, or matric potential. The energy state of water occupying the pores of a rock is described in terms of a water potential. When rock pores are not water filled, the hydrostatic pressure (or matric potential in unsaturated rock) is less than atmospheric. In this case the pressure potential is negative and work is required to remove water from the rock. The matric potential arises from capillary forces holding water in the interstices between grain boundaries, and the forces of adsorption that hold water to particle surfaces. Figures 5.5-1 and 5.5-2 show the absolute value of the matric potential.

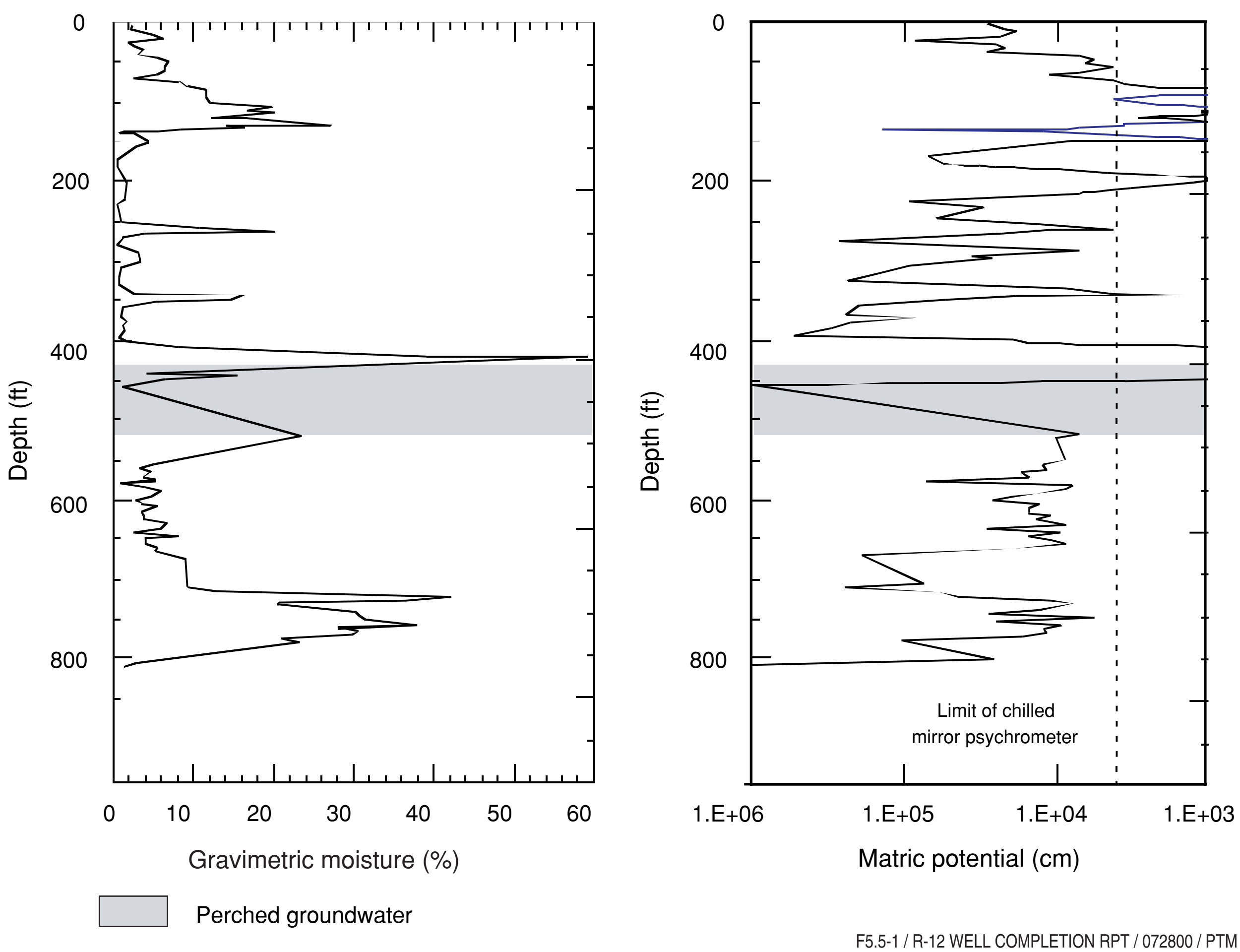


Figure 5.5-1. Gravimetric-moisture and matric-potential measurements in R-12

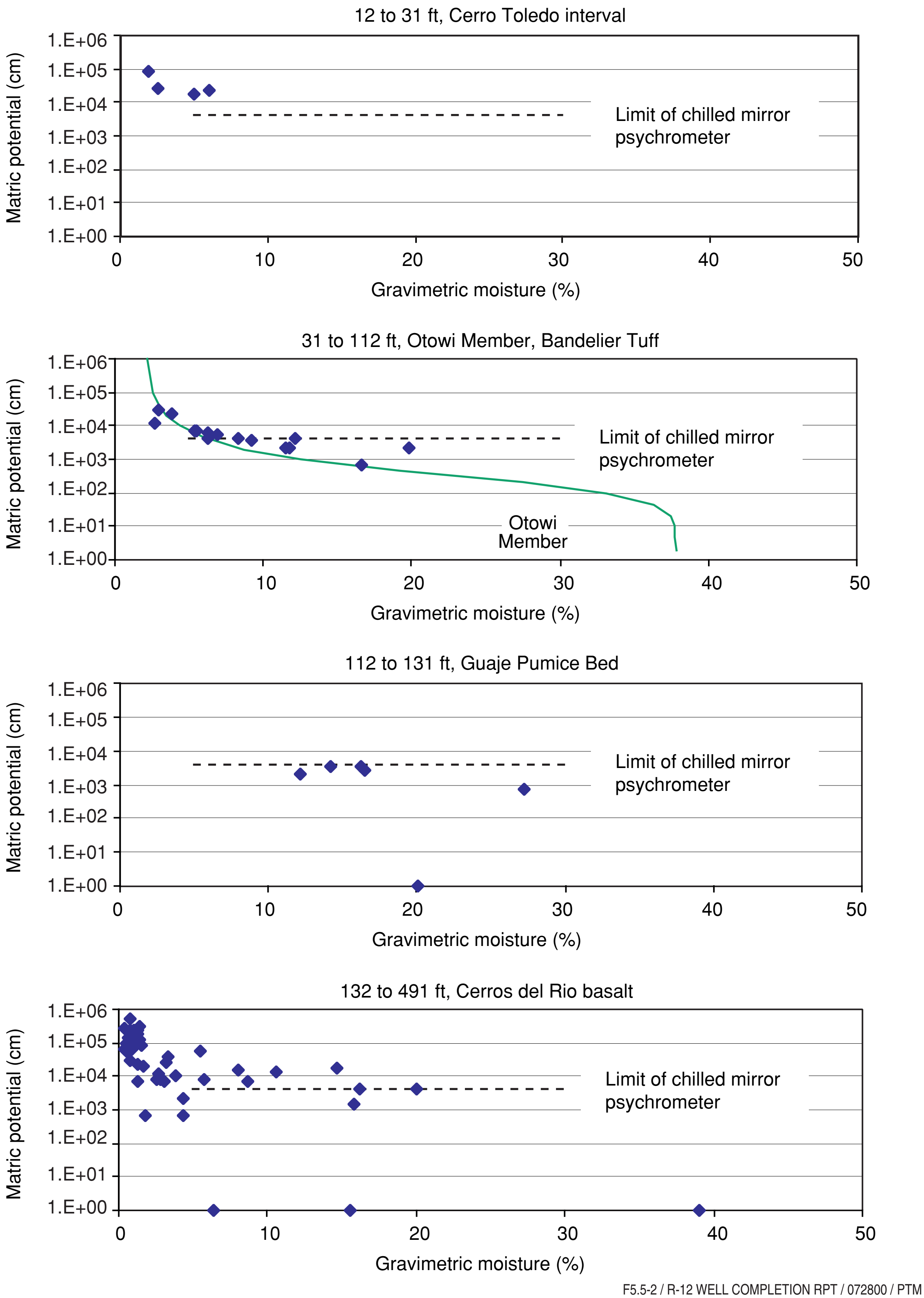


Figure 5.5-2. Gravimetric moisture and matric potential as a function of lithology in R-12

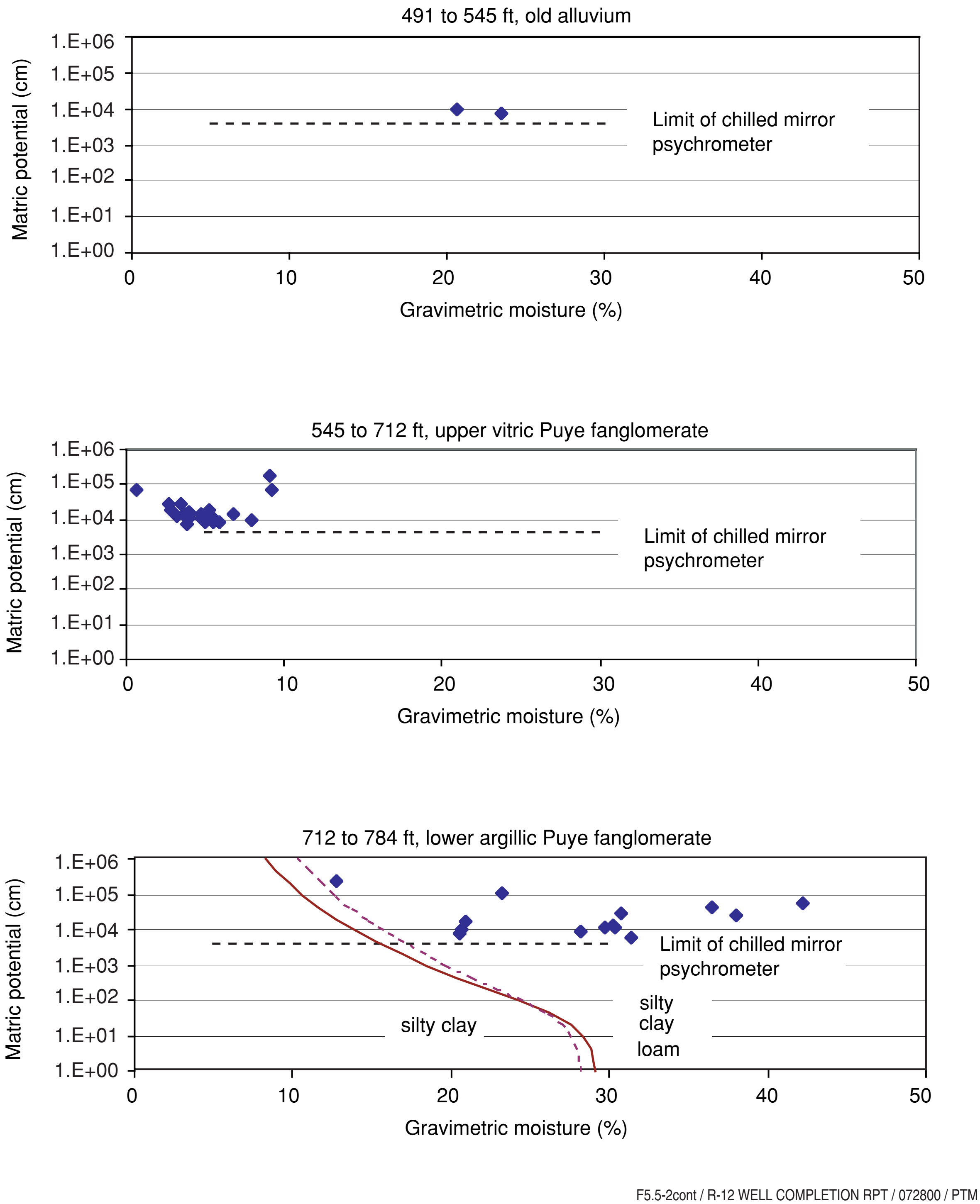


Figure 5.5-2 (continued). Gravimetric moisture and matric potential as a function of lithology in R-12

The chilled mirror psychrometer (or water activity meter) is designed for measuring matric potential in dry soils. The meter measures the water activity, which can be converted to matric potential. The units of matric potential may be given as a pressure in Pascals (Pa), or as the height of an equivalent column of water, in cm (10,200 cm H_2O = 1 MPa). The best use of the meter is for soils drier than 0.003 water activity units (-0.4 MPa or -4080 cm H_2O). This value is shown on the accompanying plots as the limit of the chilled mirror psychrometer.

5.5.1 Methods

Water potential was measured using a chilled-mirror water activity meter as described by Gee et al. (1992, 58717). Samples were doubly sealed in ziplock bags and wrapped in packing tape immediately following screening of core or cuttings for radioactivity. Storage time ranged from 2 to 49 days. Measurements were made in duplicate within 10 min after loading plastic vials with tight-fitting lids that were directly inserted into the water activity meter. Core was crushed into millimeter-sized fragments as quickly as possible after the seal was broken in order to load the vials. Repeat measurements demonstrated that samples produced the same results as long as the measurements were made less than three hours after loading the vials and securing the lids. All analytical runs were bracketed by measurements of standards, which demonstrate a 2σ reproducibility of 0.0026 for 114 analyses of the matric potential of distilled water. This is close to the instrumental precision stated in Gee et al. (1992, 58717) of 0.003 water activity units (0.4 MPa or 4080 cm H_2O). Data collected for matric-potential analyses are listed in Appendix C.

5.5.2 Results

Two methods of displaying the matric-potential data are presented here. The first is a profile of matric potential versus depth, which appears next to the moisture content data in Figure 5.5-1. The axis of the matric potential plot is reversed so that drier values appear to the left on the plot, corresponding to the direction of drier values of moisture content data. In general, the dry values of matric potential correspond to the dry moisture content measurements. The exact correspondence of potential and moisture content depends on rock texture and reflects factors like porosity and pore-size distribution.

The second method of displaying the matric-potential data is shown in Figure 5.5-2. Separate plots of matric potential versus moisture content data are provided for each stratigraphic unit. This display represents the drier portion of a moisture-retention curve. The moisture-retention curve relates the volumetric soil-moisture content of unsaturated soils and rocks to the energy state of the soil water. The water content (or gravimetric moisture content) reported here equals the mass of water divided by the dry mass of solids in a sample; to convert to volumetric moisture content, water content is multiplied by the dry bulk density of the sample.

Figure 5.5-2 shows the average moisture retention curve determined from cores by Rogers and Gallaher (1995, 49824) for the Otowi Member. This curve was converted from volumetric moisture content to water content using the average dry bulk density for the Otowi of 1.18 g/cm^3. The observed data from R-12 are in good agreement with the drier region of this curve where the chilled mirror measurements have adequate resolution.

Figure 5.5-2 shows the average moisture retention curves for the silty clay and silty clay loam soil groups from van Genuchten et al. (1991, 65419) for the lower argillic portion of the Puye Formation. These curves were converted from volumetric moisture content to water content using the porosity and an assumed grain density value. A silt loam with a porosity of 43% and a grain density of 2.6 g/cm^3 would have a calculated dry bulk density of 1.48 g/cm^3. The data for the lower argillic Puye Formation do not fall near the average values for these fine-grained soil groups or any other soil group: at a given moisture content, the Puye Formation matric-potential values are much larger. These values are also different from results for the same stratigraphic unit in well R-9. Some of the lower argillic Puye Formation samples have over 90% smectite content, based on XRD measurements. One possible explanation for the observation of high matric potentials (compared to the range reported for clay soils) for the lower argillic Puye Formation is that there may be a substantial difference in moisture-retention properties between a clay soil and a rock fabric altered to clay.

5.6 Hydraulic Properties

A total of 25 core and cuttings samples were collected and preserved for potential hydraulic-property testing and are stored at the FSF. Samples were selected for testing based on data needs identified for numerical flow and transport modeling. Potential hydraulic-property testing included, but is not limited to, porosity, particle density, bulk density, saturated hydraulic conductivity, and determination of water-retention curves. Field hydraulic-property testing focused on hydraulic conductivity of saturated zones.

5.6.1 Methods

Samples for hydraulic properties were collected as soon as possible after core extraction and were protected from moisture loss by the following methods.

- Samples for hydraulic-property testing were collected in 6-in.-diameter Lexan™ plastic or stainless-steel liners loaded into the core tube.
- If a core collected without a liner was deemed to warrant hydraulic testing, it was quickly inserted into a liner, intact if possible.
- The ends of the Lexan™ plastic or stainless-steel liners containing core to be preserved were capped with tight-fitting plastic caps and sealed with Teflon™ nonstick-coated tape.
- The capped ends of the liner were wrapped with clear packing tape.
- The footage interval of the geotechnical sample as well as the time and date of sample collection were recorded on the liner with indelible ink.
- The capped and labeled liner was inserted into a Coreprotec™ aluminized sleeve labeled with the same sampling information.
- The ends of the Coreprotec™ sleeve were melted together with an electric heat sealer, creating an air-tight seal.
- The protected cores were documented as samples for hydrologic testing, stored to prevent freezing, and transported to the FSF as soon as possible after they were collected.
- Custody of the samples was transferred from the Canyons Focus Area field support team to the FSF using a personal computer-based Access database and electronic chain-of-custody form.

5.6.2 Results

Four samples were selected for laboratory testing of hydraulic properties. This includes one from a perched zone in the Cerros del Rio basalt, one from the old alluvium, and two from the Puye Formation (Table 5.6-1). Analysis of the sample of Cerros del Rio basalt by the falling-head method yielded a saturated hydraulic conductivity of 3.9E-10 cm/sec (Stone 2000, 66781). Results of testing the other samples for the full suite of hydraulic properties are given in Appendix D.

Table 5.6-1
Samples from R-12 Selected for Testing of Hydraulic Properties

Sample Number	Geologic Unit	Depth Interval (ft)	Test
8802	Cerros del Rio basalt	489.1–489.8	Ksat[a]
8806A	old alluvium (lake beds)	520.0–520.4	H Pkg[b]
8807	Puye Formation (pumiceous sandstone)	721.0–721.5	H Pkg
8805	Puye Formation (sandstone/conglomerate)	753.0–753.4	H Pkg

[a] Ksat = tested for saturated hydraulic conductivity only; results given in text.

[b] H Pkg = tested for hydraulic package (full suite of unsaturated properties); results given in Appendix D.

5.7 Borehole Geophysics

5.7.1 Methods

The borehole geophysical methods that were used for measurements during the drilling of borehole R-12 include a color video camera, natural gamma radiation (NGR) measurements, and caliper measurements. All measurements were made inside the drill casing.

The NGR measurements provide a borehole record of the total gamma radiation. The most significant naturally occurring gamma-emitting radioisotopes are potassium-40 and daughter products of the uranium and thorium decay series. NGR measurements in boreholes are used for stratigraphic correlation and for identification of rocks and sediments that have a high abundance of clay. Uranium and thorium are concentrated in clay by the process of adsorption and ion exchange.

Caliper measurements are a record of the diameter of the borehole. The caliper record identifies features such as fractures, joints, collapse zones, and rubbly zones. The caliper record is important to the interpretation of other borehole measurements. In R-12, caliper measurements were made within the casing string to detect buildup of clay on the inside walls of the casing.

5.7.2 Results

A color video camera was used to assist in the recovery of a large steel bushing, which was accidentally dropped into the borehole to a depth of 182 ft. The camera was deployed to view the location and alignment of the steel bushing that guided the design of a tool to retrieve the bushing from the borehole. The camera was also deployed into the borehole with the tool to guide the retrieval of the steel bushing.

Measurements with the NGR probe in R-12 were taken twice during the drilling of the borehole. The first NGR measurements (Figure 5.7-1) were performed from the surface to a depth of 405 ft inside the 14-in.-diameter drill casing. The second NGR measurements (Figure 5.7-2) were taken from the surface to a depth of 640 ft inside the 10.75-in.-diameter drill casing. The 10.75-in.-diameter drill casing was telescoped inside the 14-in.-diameter drill casing with the 14-in.-diameter drill casing present to a depth of 449 ft in the borehole.

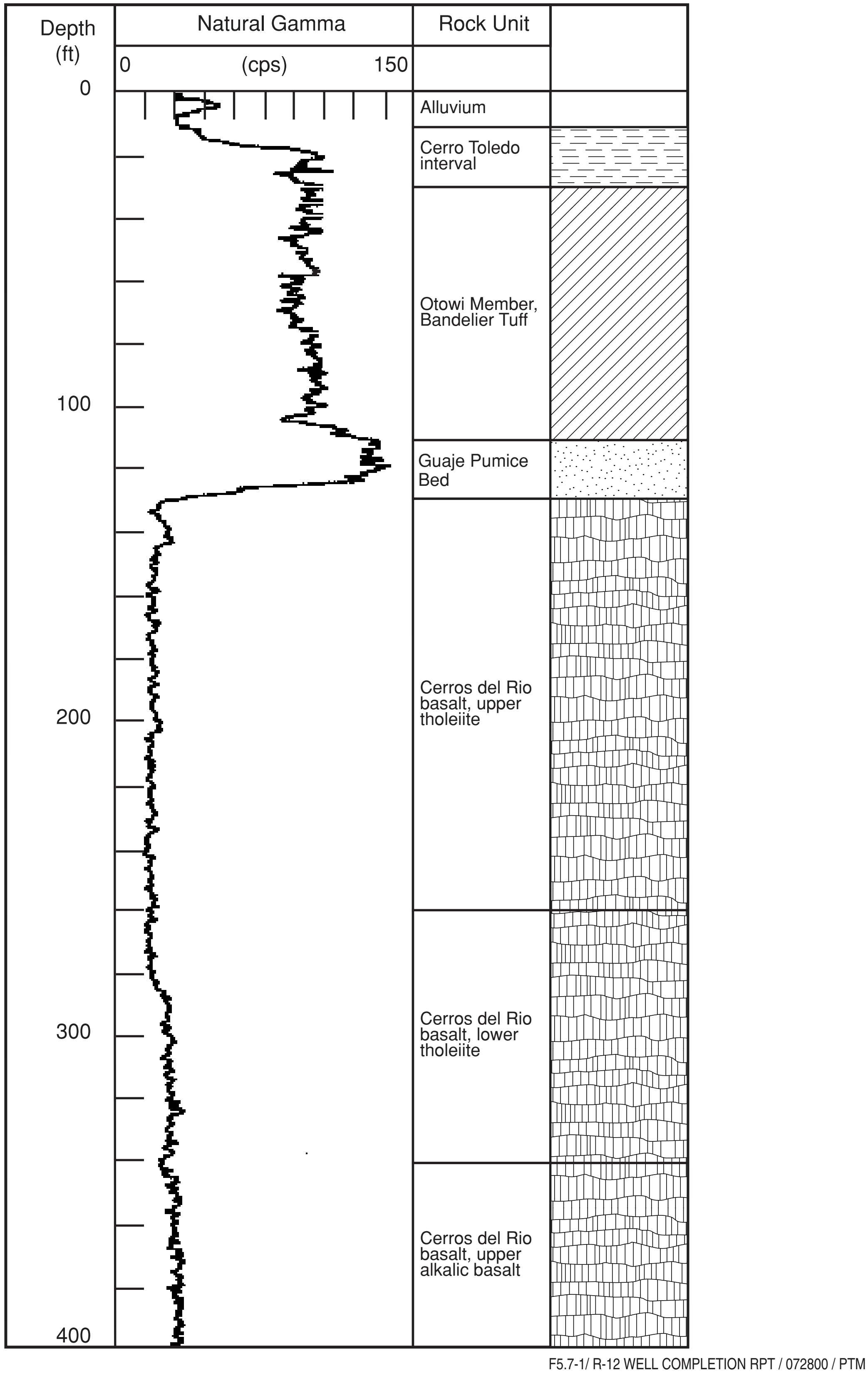
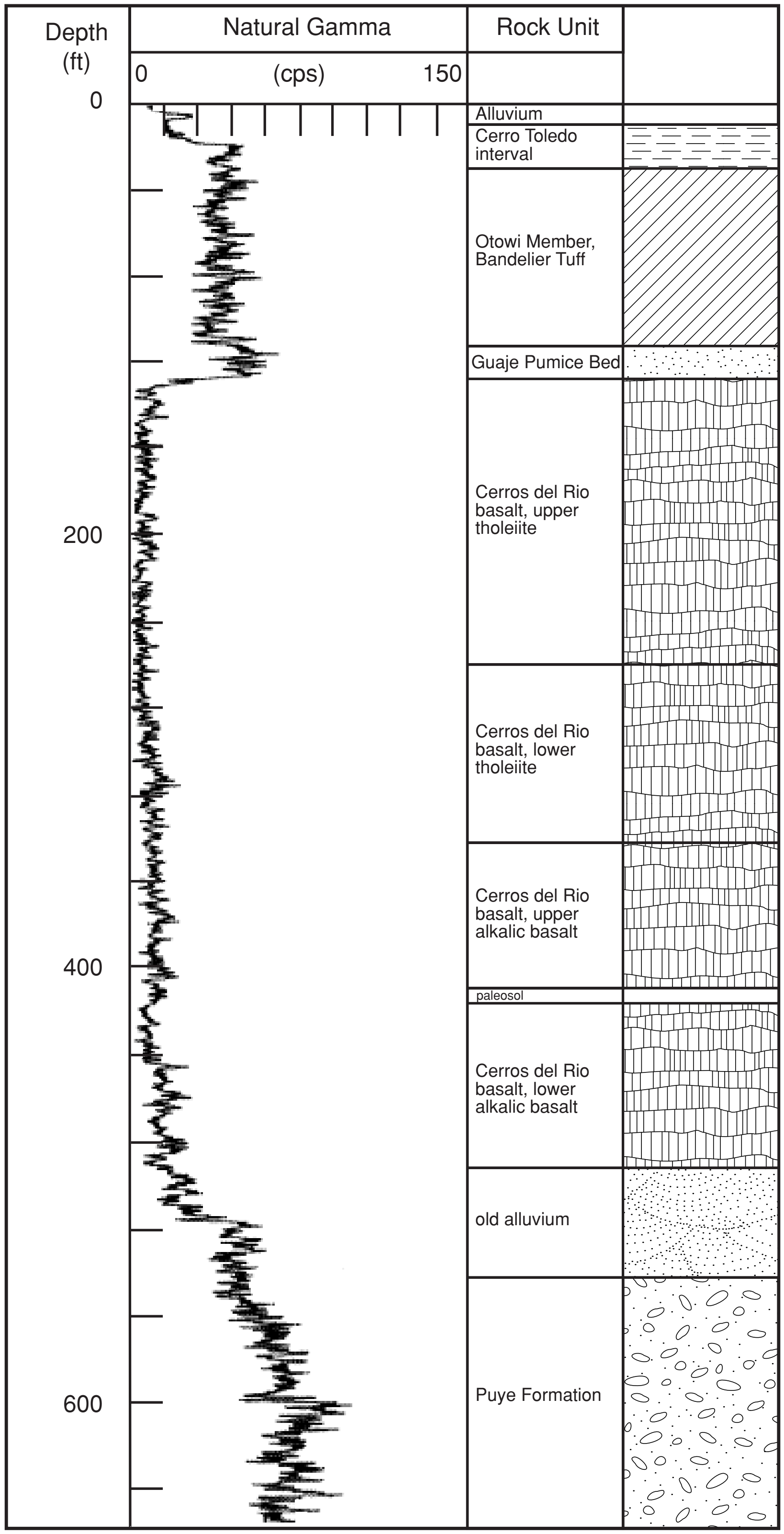


Figure 5.7-1. Borehole natural gamma measurements through 14-in.-diameter steel casing in R-12 for the depth interval of 0 to 400 ft



F5.7-2/ R-12 WELL COMPLETION RPT / 072800 / PTM

Figure 5.7-2. Borehole natural gamma measurements through 10.75-in.-diameter steel casing in R-12 for the depth interval of 0 to 650 ft

Comparison of the two figures shows a reduction in measured NGR, which occurs because of the drill casings. In Figure 5.7-1 the NGR response for the Otowi Member measured through the 14-in.-diameter drill casing is approximately 90 counts per second (cps). Figure 5.7-2 shows that the NGR response for the Otowi Member measured through both the 14-in.-diameter and the 10.75-in.-diameter drill casings is approximately 40 cps. The NGR measurements in Figure 5.7-1 for R-12 show that the highest counts of natural radiation occur in the Guaje Pumice Bed.

The Cerros del Rio basalt in R-12 has a significantly lower NGR than the Otowi Member. For NGR measurements in the 14-in.-diameter drill casing, the NGR level in the basalt along the depth interval of 136 to 280 ft was uniform with a value of 15 cps. The NGR level remains low and uniform through the total thickness of the basalt. Below the basalt, the NGR count rate gradually increases from 15 cps in the old alluvium (at a depth of 492 ft) to values of 75 cps at depths of 600 to 670 ft in the Puye Formation.

Caliper measurements in R-12 were made inside the 10.75-in.-diameter drill casing to inspect for the presence of clay-rich cuttings on the inside wall of the drill casing. The presence of clay-rich cuttings could cause anomalous NGR measurements. The 10.75-in.-diameter drill casing was the passage for drill cuttings from operation of core rods inside the 10.75-in.-diameter drill casing. The caliper record shows that the accumulation of drill cuttings inside the 10.75-in.-diameter drill casing occurred only at a depth greater than 645 ft. The effect of clay-rich materials that collected on the inside of the drill casing on the NGR measurements was limited to the depth interval of 645 to 660 ft.

6.0 WASTE MANAGEMENT

The waste generated during R-12 drilling activities included drill cuttings, purge water, decontamination water, personal protective equipment, plastic sheeting, oil-absorbent pads, and miscellaneous waste. All waste streams were managed in accordance with Laboratory-approved site-specific waste characterization strategy form (WCSF). Drill cuttings were collected in 55-gal. drums and transferred daily to roll-off bins. A total of two roll-off bins were generated from the drilling of R-12. When the bins were full, a sample was collected in accordance with the WCSF and analyzed for metals, gross alpha, gross beta, gross gamma, and tritium. The analytical results indicated the drill cuttings were not hazardous or radioactive waste. Approximately 2 yd^3 of drill cuttings were generated during the second phase of drilling, when the borehole was deepened to accommodate the permanent well casing. These cuttings were characterized as not hazardous or radioactive waste based on results from previous sampling of drill cuttings during the initial phase of drilling and spread on the ground surface as part of final site restoration.

Drilling in the perched-water zone and the regional aquifer during the first phase of drilling generated approximately 4000 gal. of groundwater. Water generated was temporarily stored onsite in two 3000-gal. tanks, sampled, and discharged to the site in accordance with the WCSF and the New Mexico Environment Department (NMED) -approved Notice of Intent (NOI) to discharge. During the second phase of drilling, the borehole was deepened to accommodate the permanent well casing and approximately 3500 gal. of groundwater were generated. This water was direct-discharged based on prior characterization and in accordance with the approved NOI. In addition, approximately 2000 gal. of groundwater were generated during well development and hydrologic testing. This water was also direct-discharged based on prior characterization and in accordance with the approved NOI.

Decontamination water (less than 6 gal./day) was periodically generated from cleaning sampling and monitoring equipment (i.e., core tubes, bailers, water-level meter) onsite. This water was discharged to the site in accordance with "Decontamination Water Discharge Procedure: Containerized Decon Water" (LANL

1996, 58716) and the approved WCSF, based on visual observation and field screening. Large equipment and the drill pipe were cleaned at TA-50, as needed.

Miscellaneous waste included nitrile gloves, paper towels, plastic bags, and plastic sheeting. These materials were placed in plastic drum liners and labeled with the well designation, generation dates, borehole depths, and contents. Approximately five 55-gal. drum liners of miscellaneous waste were generated during drilling. A waste profile form was prepared for this waste stream, and the miscellaneous waste was disposed of at the Los Alamos County landfill in accordance with the approved WCSF.

Plastic sheeting and sorbent pads used beneath the drill rig and heavy equipment to contain any leaking hydraulic fluid, lubricants, and antifreeze were contained in three 55-gal. drums and managed and disposed of as New Mexico special waste.

In addition, the following unanticipated waste streams were generated and processed in accordance with general waste management guidance, applicable Laboratory procedures, and federal and state regulations.

Two drums of decontamination water were generated from cleaning unused auger flights, which were sprayed by hydraulic fluid when a hydraulic line ruptured, and the water was managed appropriately.

A total of eighteen 55-gal. drums of excavated soil that was contaminated with spilled diesel fuel was managed and disposed of as New Mexico special waste.

7.0 SURVEY ACTIVITIES

7.1 Geodetic Survey

The location of R-12 was determined by geodetic survey on September 20, 2000, using a Wild/Leica TC1600 total station. Control was second-order, class II monuments placed by Johnson Controls Northern New Mexico; these second order monuments were derived from the 1992/1993 Laboratory-wide control network. The survey located the brass monument in the northwest corner of the well pad and the north side of top of well casing (Table 7.1-1). Horizontal well coordinates are based on New Mexico State Plane Grid Coordinates, Central Zone (North American Datum 83) and are expressed in feet. Elevation is expressed in feet above mean sea level using the National Geodetic Vertical Datum of 1929. The Facility for Information Management, Analysis, and Display (FIMAD) location identification number for R-12 is SA-00006.

Table 7.1-1
Geodetic Data for Well R-12

	Northing (ft)	Easting (ft)	Elevation (ft)
Brass Monument	1767913.4	1647424.2	6499.6
Top of Casing	1767908.9	1647429.3	6501.03

7.2 Surface Radiological Survey

A surface radiological survey was conducted by a radiological control technician before drilling activities began at SCOI-3, which was initially installed before R-12. The predrilling radiation survey was conducted on May 6, 1996, and consisted of collecting alpha, beta, and gamma background measurements and conducting statistical analysis to calculate action levels. Established action levels are used as a basis to determine if borehole materials screened during drilling exhibit radioactivity above surface background values. The survey consisted of 15 points on a grid projected over the work area. Each point was surveyed using direct reading alpha, beta/gamma, and dose rate meters. Alpha was measured using a Ludlum Model 139 with air proportional probe; beta/gamma was measured using a Ludlum Model 12 with 44-9 probe; dose rate was measured using a Ludlum Model 19 μR/hr meter. Calculated background values for the drill site are 0.4 cpm for alpha, 154 cpm for beta/gamma, and 14.8 μR/hr for dose rate.

8.0 WELL DESIGN, CONSTRUCTION, AND DEVELOPMENT

8.1 Well Design

Drilling of borehole R-12 began on March 9, 1998, and was completed on January 10, 2000. Drilling was temporarily halted on June 9, 1998, at a depth of 847 ft for further evaluation of combined data from R-9 and R-12 by the Canyons Focus Area Technical Team and the Groundwater Integration Team to develop a final design for approval by the regulators. After discussions between the Laboratory, the US Department of Energy (DOE), and NMED, the decision was made to halt further work on R-12 until relationships at the top of the regional zone of saturation could be better determined. The principal concern at this time was that the well screen might be improperly positioned to sample the top of the regional zone of saturation. As a result, a temporary PVC casing was installed to provide access to water samples and to provide a stable environment for a pressure transducer to monitor water levels until the completion strategy for the permanent well could be finalized. The temporary well completion for R-12 is shown in Figure 8.1-1. The temporary well at R-12 was constructed in the following manner. The final phase of drilling at R-12 took place from October 25, 1999, to January 10, 2000.

- Approximately 100 gal. of water was air-lifted out of the borehole and casing in preparation for well installation.
- The PVC well casing for the temporary well was delivered to the site and assembled in 20-ft sections; all joints were measured and inspected.
- A 1-in. tremie line was tripped into the casing to 800 ft to emplace bentonite and filter-pack materials. The bottom of the borehole was backfilled with sand, and a bentonite bottom seal was emplaced above the fill.
- A 4-in.-inside diameter (I.D.) schedule 40 PVC monitoring-well casing was tripped in and landed at a depth of 829 ft.
- The well was constructed as the 8 5/8-in.-diameter drill casing was retracted.
- The completed well consists of a 10.5-ft sump, a 20-ft section of 10-slot well screen (0.010-in.) that extends from depths of 800 to 820 ft, and a filter pack consisting of 30-70 grade sand.
- The constructed well was developed by bailing 450 gal. of water from the screened interval.
- A pressure transducer was installed to monitor water table fluctuations because of atmospheric effects, seasonal effects, earth tides, and pumping of nearby water supply well PM-1.

Data collected from wells R-9 and R-12 were evaluated and a final completion strategy for R-12 was proposed by the Groundwater Integration Team. This completion strategy was discussed with DOE and NMED, and the completion of R-12 was scheduled for the early part of fiscal year 2000. The final phase of drilling and well installation at R-12 took place from October 25, 1999, to January 21, 2000.

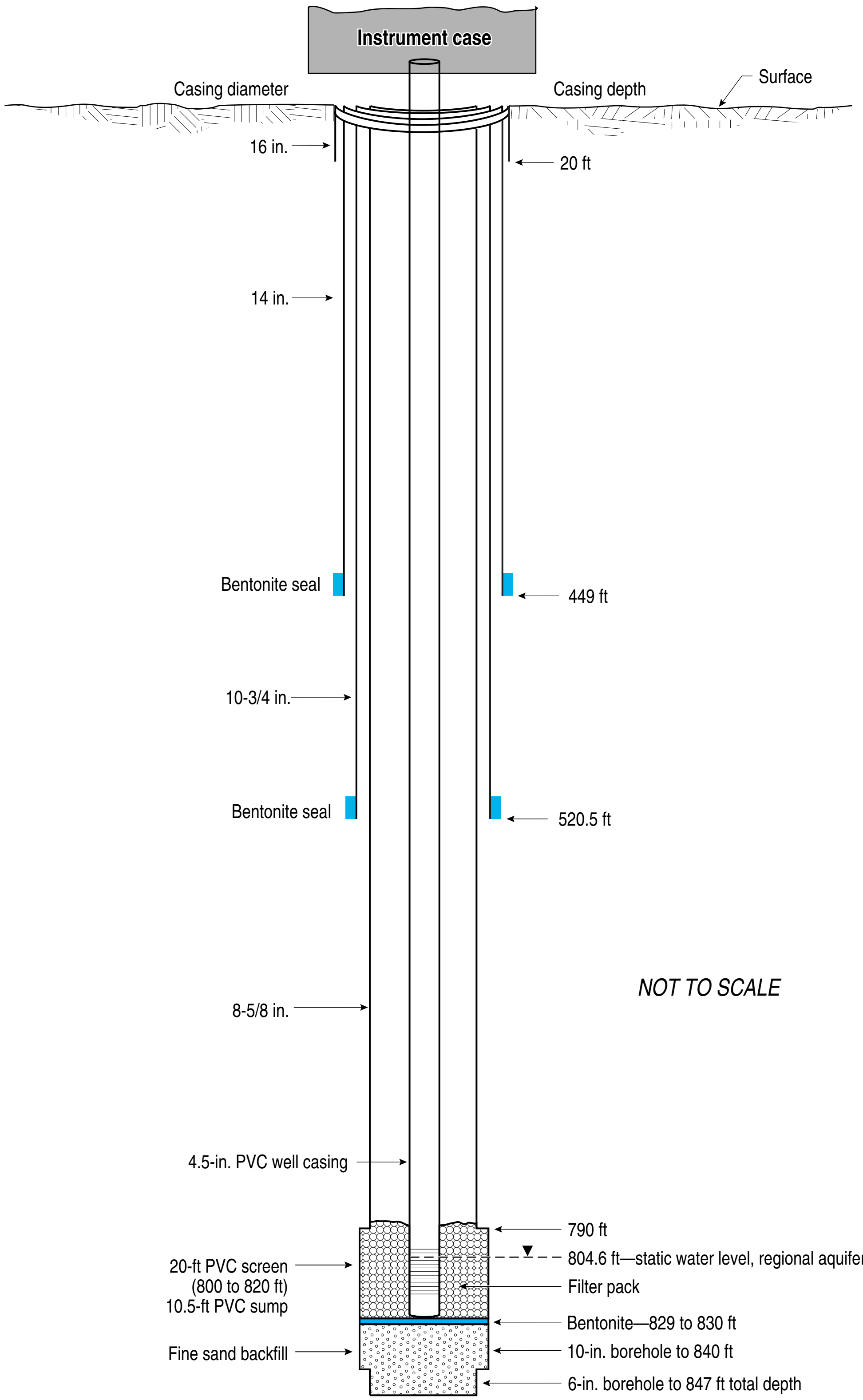


Figure 8.1-1. Configuration of the temporary well for R-12

8.2 Well Construction

During the final stages of drilling and well completion, the temporary PVC well was removed, and the borehole was deepened from 847 ft to 886 ft to accommodate the final well design for the permanent characterization well. Well construction was conducted from January 11, 2000, to January 21, 2000. At total depth the R-12 borehole contained three telescoped drill casings with diameters of 14 in., 11.75 in., and 9.625 in. The drill casings were retracted as annular backfill materials were emplaced around the well casing. The 14-in. drill casing could not be retracted from its original landed depth of 450 ft and was grouted in place in the borehole. All backfill materials were emplaced through a tremie pipe.

Well R-12 was constructed of 5-in.-outside diameter (O.D.) 304 stainless-steel flush-threaded casing within the saturated zones and schedule 40 low-carbon steel casing above the saturated zones. Well R-12 was designed and constructed with three screened intervals. The upper-most screen, screen #1, is positioned at a depth of 459 to 469 ft bgs and is located within Cerros del Rio basalt in the upper part of the perched groundwater zone. Screen #2 is positioned at a depth of 504 to 509 ft bgs and is located within old alluvium sediments in the lower part of the perched zone. Screen #3 is located at the top of the regional zone of saturation at a depth of 800 to 839 ft bgs. This places the top of screen #3 approximately 5 ft above the top of the current static water level in the regional groundwater system. Screens #1 and #3 are constructed of 0.010-in. slot, 80-rod, wire-wrapped, 304 stainless steel. Screen #2 is 0.005-in. slot, 80-rod, wire-wrapped, 304 stainless steel. A 30-ft sump was installed below screen #3 to the bottom of the well to accommodate the Westbay multilevel monitoring system. The total depth of the well is 869 ft bgs. The as-built well completion drawing for R-12 is shown in Figure 8.1-2.

8.3 Well Development

Well development was conducted on February 5 and 6, 2000. Well development methods involved jetting and pumping. Each of the screened intervals was jetted with municipal water using a UDR-20 drill rig and specialized jetting tool on NQ drill rod. A total of approximately 2000 gal. of municipal-supply water was used during the jetting process. Following jetting, a submersible pump was deployed and the well was pumped to remove sediment and reduce turbidity to less than 5 nephelometric turbidity units (NTUs). A total of 1613 gal. of water was pumped from the well during development at a rate of approximately 10 gal. per minute. Turbidity was reduced from 30.5 NTU to less than 1 NTU at completion. Turbidity values in NTUs with respect to volume of water pumped in gallons are shown in Figure 8.2-1.

Following well development, the Westbay MP55 System® for groundwater monitoring was installed in the steel-cased well. Model 2523 MOSDAX® System sampler probe equipment will be used to collect groundwater samples from the completed well.

An MP casing installation log, which specifies the location of each Westbay well component in the borehole, was prepared in the field by Westbay in consultation with the Laboratory, based on a draft of the well-completion diagram. Available geophysics logs and an as-built video log taken inside the steel well casing were also reviewed prior to siting measurement ports and packers within the well screen intervals. The final version of the MP casing installation log was approved in the field on March 1, 2000, by the Laboratory prior to installation of the Westbay well components. The MP casing installation log as approved was used as the installation guide in the field.

An MP measurement port coupling and associated magnetic location collar were included in each primary monitoring zone to provide the capability to measure fluid pressures and collect fluid samples. A pumping port coupling was also included in the three primary zones to provide purging, sampling, and hydraulic conductivity testing capabilities. Additional measurement port couplings were included below the pumping ports in screens #1 and #2 for monitoring hydraulic tests. Additional measurement ports and a second pumping port were included in screen #3 to provide monitoring capabilities during the expected slow decline of water levels in the regional aquifer.

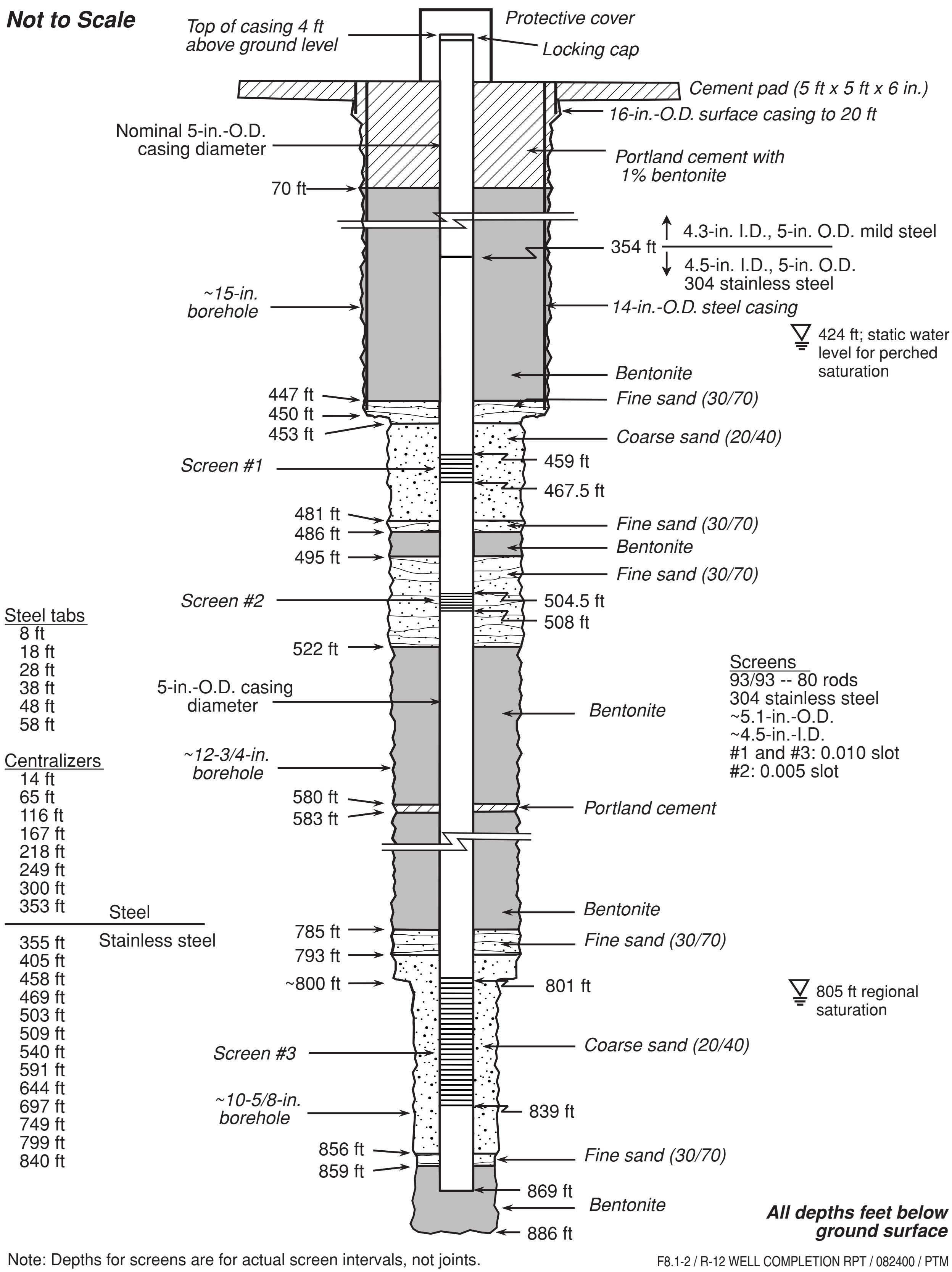


Figure 8.1-2. As-built well completion diagram of well R-12

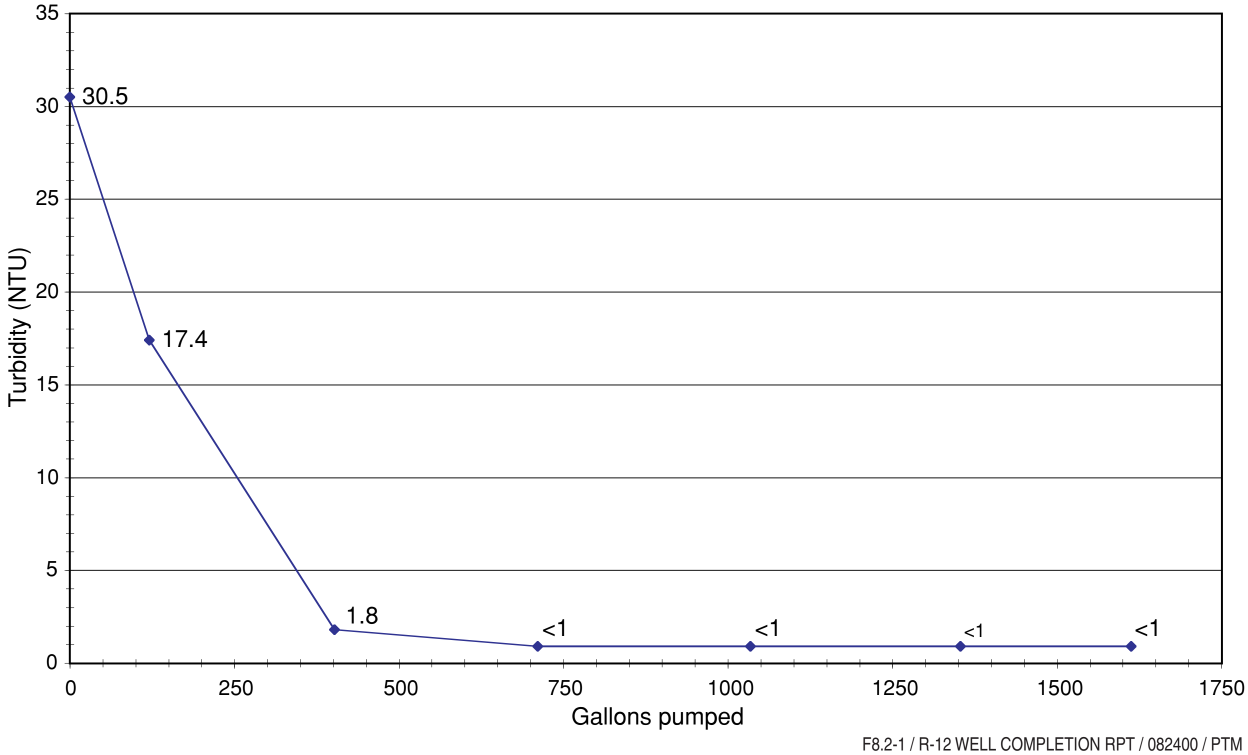


Figure 8.2-1. Well R-12 pumping development

Measurement port couplings were included in quality assurance (QA) zones to provide QA testing capabilities. All measurement ports were positioned below each of the MP55 packers to permit routine operation of the squeeze relief venting with the MP55 packer inflation equipment during the inflation process.

The MP casing components were set out in sequence according to the MP casing installation log on racks near the borehole. Each casing length was numbered in order beginning with the lowermost as an aid in confirming the proper sequence of components. The appropriate MP system coupling was attached to each piece of MP casing. Magnetic location collars were attached 2.5 ft below the measurement ports in each of the primary monitoring zones and 2.5 ft below MP coupling No. 99 near the top of the well.

The length of each MP casing section was measured with a steel tape to confirm nominal lengths, and the data were entered on the MP casing installation log. Each casing component was visually inspected, and serial numbers for each packer, measurement port coupling, and pumping port coupling were recorded on the field copy of the MP casing installation log.

The MP casing components were lowered into the well in sequence. The first 15 sections of MP casing were lowered by hand, and a Smeal work-over rig provided by the Laboratory was used to lower the remaining MP casing components. Each casing joint was tested with a minimum internal pressure of 300 psi for one min to confirm hydraulic seals. Deionized water was used for the joint tests. Each successful joint test and the placement of each casing component are recorded in the field copy of the MP casing installation log. The suspended weight of the MP casing components was monitored during lowering to confirm that operating limits of the MP system casing components were not exceeded. Lowering the MP casing to the target position was successfully completed on March 17, 2000.

After the casing was lowered into the borehole, the water level inside the MP casing was left at a depth of more than 713 ft below the top of the MP casing to confirm hydraulic integrity of the casing. The open-hole water level was 805 ft below ground level. With this differential pressure acting on the MP casing string, the water level inside the MP casing was essentially stable over night. The test indicated that the MP casing was water tight.

After the components were lowered into the well and the hydraulic integrity of the MP casing had been confirmed, the MP casing string was positioned as shown in Appendix E. The MP packers were inflated on March 19, 2000, using deionized water. The packers were inflated in sequence, beginning with the lowermost. All of the packers were inflated successfully and QA tests showed that all of the packer valves were closed and sealed.

Westbay's procedure for destressing the MP casing was used after all of the packers had been inflated. The top MP55 casing (No. 102) was cut and trimmed to suit the final configuration of the wellhead assembly and the MP top completion was installed. The final length of MP casing No. 102 was 0.6 ft. The final tensile load at the top of the MP casing was 250 lb. The maximum limit for long-term tensile loading of the MP casing is 1000 lb (454 kg). A sketch of the as-built top of the MP casing and final positions of the MP well components are shown in Appendix E. A summary of depth information for key MP well components is shown on Table 8.2-1.

After packer inflation was completed, fluid pressures were measured at each measurement port. The fluid-pressure profile measurements were taken on March 21, 2000. At that time, the in situ formation pressures may not have recovered from the preinstallation and installation activities. Longer-term monitoring may be required to establish representative fluid pressures.

A plot of the piezometric levels in all zones including QA zones, based on the March 21 pressure measurements, was examined to confirm proper operation of the measurement ports and as a check on the presence of annulus seals between adjacent monitoring zones. All of the measurement ports operated normally. Each of the packers was supporting a differential hydraulic pressure, indicating the presence of packer seals.

8.4 Wellhead Protection

A reinforced concrete vault was installed to provide wellhead protection. Figure 8.3-1 shows plan and profile views of the well-head configuration.

9.0 SITE RESTORATION

The R-12 drill site area was recontoured to match the surrounding topography using a backhoe. The surface of the drill pad was roughened and native dryland seed was applied to the denuded areas. Straw mulch was then spread over the seeded areas and wheel-rolled to crimp in the straw and cover the seed.

10.0 MODIFICATIONS TO WORK PLANS

Table 10.0-1 compares the planned characterization activities in the "Task/Site Work Plan for Operable Unit 1049: Los Alamos Canyon and Pueblo Canyon" (LANL 1995, 50290), the "Hydrogeologic Workplan" (LANL 1998, 59599), the core document (LANL 1997, 55622), and the "Field Implementation Plan for the Drilling and Testing of LANL Regional Characterization Well R-12" ("the field implementation plan"; LANL 1998, 59162) with characterization activities performed in R-12. The characterization activities in the hydrogeologic work plan and the core document are the same; therefore, planned characterization activities for these two documents are shown together in Table 10.0-1.

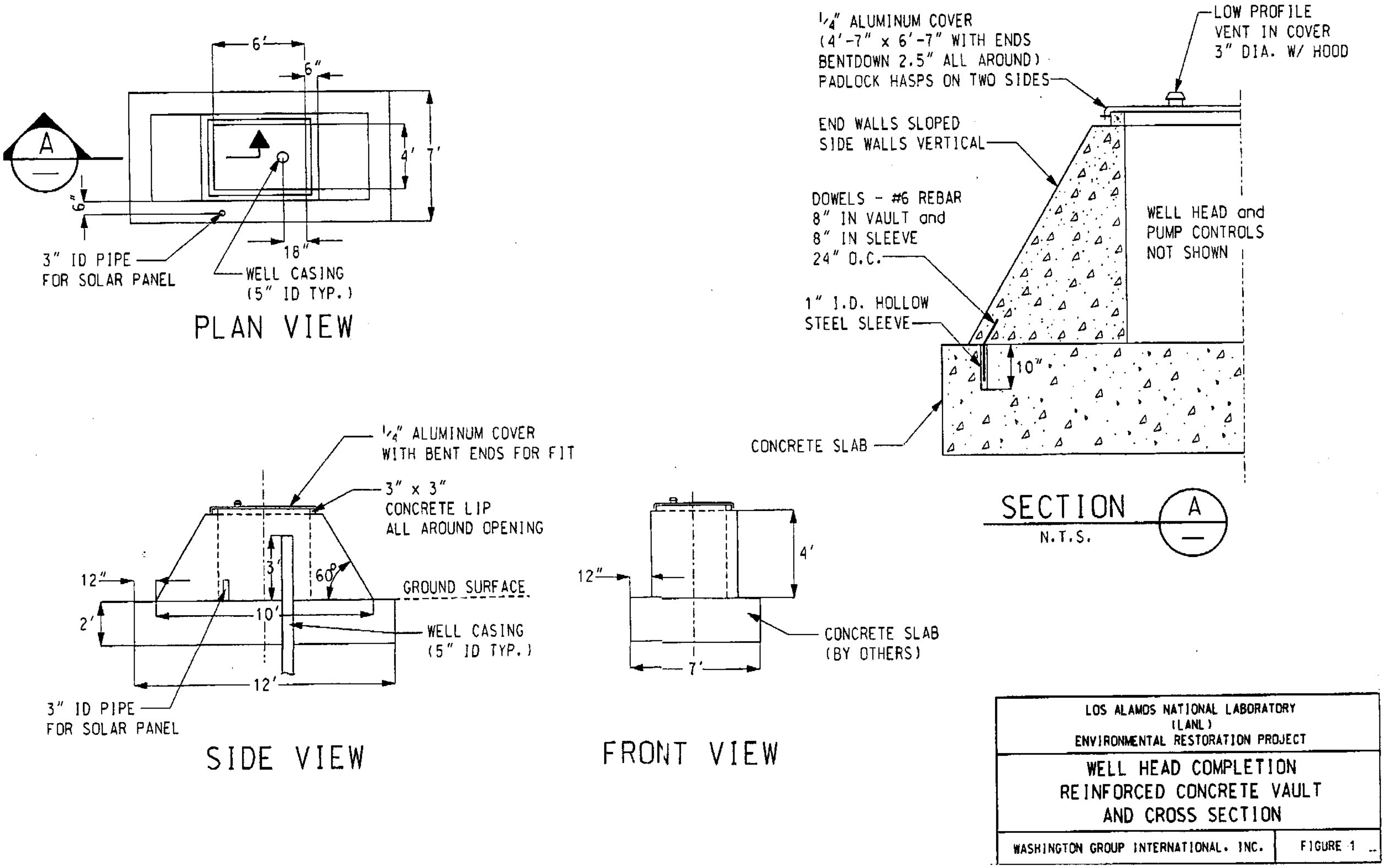
Table 8.2-1
Depths of Key Items Installed During R-12 MP55 Completion

Zone No.	Screen Interval[a] (ft)	Sand Pack Interval[a] (ft)	MP Casing No. (from MP Log)	Packer No.	Packer Serial No.	Nominal Packer Position[b] (ft)	Magnetic Collar Depth (ft)	Measurement Port Depth[b] (ft)	Pumping Port Depth[b] (ft)	Port Name
			55	1	0611-132	443.9–448.4				
SQA1	Blank		54				None	448.4	None	SQA1
			53	2	0611-136	453.7 – 458.2				
Zone 1	459.9–468.5	447–486	51				470.6	468.1		MP1A
			50						473.5	PP1
			49					479.1		MP1B
			48	3	0611-133	482.8 – 487.3				
SQA2	Blank		47				None	487.3	None	SQA2
			44	4	0611-137	499.2 – 503.7				
Zone 2	504.9–508.0	495–522	42				509.25	507.0		MP2A
			41						512.4	PP2
			40					518.0		MP2B
			39	5	0611-130	521.7 – 526.2				
SQA3	Blank		38				None	526.2	None	SQA3
			11	6	0611-134	781.7 – 786.1				
LQA3	Blank		10				None	786.1	None	LQA3
			9	7	0611-135	791.5 – 796.0				
Zone 3	830.1–839.5	785–859	6				813.05	810.8		MP3A
			5						816.2	PP3A
			4					821.8		MP3B
			3						827.2	PP3B
			2				835.15	832.9		MP3C

Note: Blanks indicate no data.

[a] All depths are with respect to ground level.

[b] All depths of MP system casing components are the depth to the top of the respective couplings.



F8.3-1 / R-12 WELL COMPLETION RPT / 082400 / PTM

Figure 8.3-1. **Well R-12 wellhead diagram**

Table 10.0-1
Activities Planned for R-12 Compared with Work Performed

	Work Plan for Los Alamos Canyon and Pueblo Canyon	Hydrogeologic Work Plan and Core Document for Canyons Investigations	R-12 Field Implementation Plan	R-12 Actual Work
Planned Depth (ft)	450	100 to 500 into the regional aquifer	Nominally 1000	881
Drilling Method	Auger or rotary drilling	Methods may include, but are not limited to, hollow-stem auger (HSA), air-rotary/Odex/Stratex, air-rotary/Barber rig, mud-rotary drilling	Air-rotary methods including downhole percussion hammers on 4.5-in.- and 7-in.-O.D. dual-wall casings to drill open hole; air-rotary 101-mm Geobarrel system to collect continuous core; air-rotary Holte and Stratex casing-advance systems and downhole percussion hammers to simultaneously drill and advance casing in the borehole	Same as field implementation plan
Amount of Core	Not specified	100% of the borehole	Approximately 50% of the borehole	11.4% of R-12; 26.4% for this location when core from SCOI-3 is included
Lithologic Log	Log to be prepared from core, cuttings, drilling performance	Log to be prepared from core, cuttings, drilling performance	Log to be prepared from core, cuttings, drilling performance	Log was prepared from core, cuttings, geophysics logs, and drilling performance.
Number of Water Samples Collected for Contaminant Analysis	A water sample will be collected from each saturated zone. Well to be sampled at completion and at six months.	A water sample will be collected from each saturated zone. The number of sampling events after well completion are not specified.	A water sample will be collected from each saturated zone. The geochemistry project leader and technical team will determine the number and locations of samples based on conditions encountered. The number of sampling events after well completion are not specified. Up to six water samples are planned.	Four water samples were collected from saturated zones during drilling.
Water Sample Analytes	**Trace Elements/Metals:** Al, Sb, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Ag, Na, Tl, Ti, U, V, Zn **Anions:** Br, ClO_3, Cl, F, NO_3, PO_4, HCO_3, SO_4 **Other Inorganic Chemicals:** Si, cyanide **Radionuclides:** ^{3}H, ^{90}Sr, ^{137}Cs, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, ^{241}Am **Organic Compounds**: pesticides, PCBs, VOCs, SVOCs **Other Analyses:** ^{14}C, ^{13}C, $^{18}O/^{16}O$, D/H, DOC	Radiochemistry I, II, and II analytes; ^{3}H, gamma spectroscopy scan; general inorganic chemicals; metals; stable isotopes	**Trace Elements/Metals:** Al, Sb, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Ag, Na, Tl, U, V, Zn, NH^4 **Anions:** Br, ClO_3, Cl, F, NO_3, NO_2, PO_4, HCO_3, SO_4 **Other Inorganic Chemicals:** Si, cyanide, total organic carbon **Radionuclides:** ^{3}H, ^{90}Sr, ^{137}Cs, ^{241}Am, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, gamma spectroscopy, gross-alpha, gross-beta, gross gamma **Organic Compounds:** VOCs, SVOCs **Other Analyses:** ^{14}C, ^{13}C, $^{18}O/^{16}O$, D/H, DOC	Same as field implementation plan with additions of Mo and $^{15}N/^{14}N$

Table 10.0-1 (continued)

	Work Plan for Los Alamos Canyon and Pueblo Canyon	Hydrogeologic Work Plan and Core Document for Canyons Investigations	R-12 Field Implementation Plan	R-12 Actual Work
Water Sample Field Measurements	Alkalinity, dissolved oxygen, pH, specific conductance, temperature, turbidity	Alkalinity, pH, specific conductance, temperature, turbidity	Alkalinity, dissolved oxygen (completed well only), pH, specific conductance, temperature, turbidity	Alkalinity, pH, specific conductance, temperature, turbidity
Number of Core/Cuttings Samples Collected for Contaminant Analysis	Collect and preserve seven cores to represent major hydrogeologic units and zones above and below major hydrogeologic contacts	Twenty samples of core or cuttings to be analyzed for contaminants in each borehole	Up to 23 core/cuttings samples planned; number of samples dependant on number of saturated zones encountered	14 samples of cores/cutting have been collected for contaminant analysis.
Core Sample Analytes	**Trace Elements/Metals:** Al, Sb, As, Ba, Be, Br, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Ni, K, Se, Ag, Na, Tl, Ti, U, V, Zn **Anions:** B, Cl, F, SO_4 **Other Inorganic Chemicals:** Si, cyanide **Radionuclides:** ^{3}H, ^{90}Sr, ^{137}Cs, ^{230}Th, ^{232}Th, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, gamma spectroscopy, gross-alpha, gross-beta, gross gamma	Uppermost sample to be analyzed for a full range of compounds; deeper samples to be analyzed for radiochemistry I, II, and II analytes; ^{3}H; and metals; four samples to be analyzed for VOCs	**Trace Elements/Metals:** Al, Sb, As, Ba, Be, Cd, Cr, Co, Cu, Fe, Pb, Mn, Hg, Mo, Ni, Se, Ag, Tl, U, V, Zn **Anions:** Br, Cl, F, SO_4, NO_3 **Other Inorganic Chemicals:** cyanide **Radionuclides:** ^{3}H, ^{90}Sr, ^{137}Cs, ^{241}Am, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, $^{239,240}Pu$, gamma spectroscopy, gross-alpha, gross-beta, gross gamma VOCs and SVOCs to be determined in four samples and where PID detects occur	Same as field implementation plan
Laboratory Hydraulic Tests	Bulk density, dry density, Kd, porosity, mineralogy, moisture content, moisture potential, saturated hydraulic conductivity	Physical properties to be determined on 5 samples and will typically include moisture content, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics. Approximately 10 samples of core or cuttings will be collected for mineralogy, petrography, and rock chemistry.	The following physical properties will be determined in each of the major stratigraphic units: particle size (sedimentary units) moisture content, matric potential, porosity, particle density, bulk density, saturated hydraulic conductivity, and water retention characteristics. In addition, approximately 15 samples of core or cuttings will be selected by the geology project leader for mineralogy, petrography, and rock chemistry.	112 samples were analyzed for moisture content, 111 samples for matric potential, 1 for saturated hydraulic conductivity, and 3 for the full suite of unsaturated hydraulic properties. Additional cores have been preserved for possible future testing.
Geology		Approximately 10 samples of core or cuttings will be collected for mineralogy, petrography, and rock chemistry.	Approximately 15 samples of core or cuttings will be selected by the geology task leader for mineralogy, petrography, and rock chemistry.	A total of 23 samples were characterized for mineralogy, petrography, and rock chemistry.

Table 10.0-1 (continued)

	Work Plan for Los Alamos Canyon and Pueblo Canyon	Hydrogeologic Work Plan and Core Document for Canyons Investigations	R-12 Field Implementation Plan	R-12 Actual Work
Geophysics	Natural gamma, neutron moisture, and density logs may be collected.	In general, open-hole geophysics includes caliper, electromagnetic induction, natural gamma, magnetic susceptibility, borehole color videotape, fluid temperature (saturated), fluid resistivity (saturated), single-point resistivity (saturated), and spontaneous potential (saturated). In general, cased-hole geophysics includes gamma-gamma density, natural gamma, and thermal neutron.	In stable open-borehole environments, geophysics measurements will include caliper, electromagnetic induction, natural gamma, magnetic susceptibility, color camera, borehole digital camera, gamma-gamma, and thermal/epithermal neutron logs. In the cased borehole, geophysics measurements will include gamma-gamma density, natural gamma, and thermal neutron logs.	Same as field implementation plan
Water-Level Measurements			Waters levels will be determined for each saturated zone by water-level meter or by pressure transducer.	Water levels were determined for each saturated zone by water-level meter or by pressure transducer.
Field Hydraulic Tests			Slug tests planned for all zones of saturation encountered.	A slug test was not appropriate for the perched zone as it would possibly span confined and unconfined conditions. Injection tests were conducted for both the perched and regional zones of saturation.
Air Permeability/ Borehole Anemometry		Conducted in Bandelier Tuff at 10-ft intervals after removing the HSA and/or Odex/Stratex casing	In unsaturated environments, borehole anemometry and straddle packer air-permeability measurements will be made in stable open-borehole environments at locations determined in the field.	Anemometry and air permeability were not measured.
Surface Casing		Approximately 20-in. O.D., extends from land surface to 10-ft depth in underlying competent layer and grouted in place	10-in.-diameter low-carbon steel casing set to a minimum depth of 20 ft with a 3-ft stickup	16-in. surface casing extends to a depth of 20 ft.
Minimum Well Casing Size	4 in.	6-5/8-in. O.D.	5-in. I.D.	4.3-in. I.D., 5-in. O.D. above 354 ft; 4.5-in. I.D., 5-in. O.D. below 354 ft.

Table 10.0-1 (continued)

	Work Plan for Los Alamos Canyon and Pueblo Canyon	Hydrogeologic Work Plan and Core Document for Canyons Investigations	R-12 Field Implementation Plan	R-12 Actual Work
Well Screen	10-ft stainless steel with top at top of static water level	Machine-slotted (0.01-in.) stainless-steel screens with flush-jointed threads; number and length of screens to be determined on a site-specific basis and proposed to NMED	60 ft of prepacked, 6.68-in.-diameter, machine-slotted (0.01-in.) stainless-steel screen with flush-jointed threads 5 ft of the screen to extend above the static water level; screen specifications based on well-life expectancy of 50 years and on discussions with NMED	40 ft (joint to joint) of wire-wrapped stainless-steel screen, 0.01-in. slots
Filter Material		>90% silica sand, properly sized for the 0.010-in. slot size of the well screen; extends 2 feet above and below the well screen	>98% silica sand, properly- sized for the 0.010-in. slot size of the well screen; extends 2 ft above and below the well screen	20/40 sand from 8 ft above screen to 17 ft below screen
Conductor Casing		Carbon-steel casing from land surface to top of stainless-steel casing	Carbon-steel casing 5.56-in. in diameter extending from land surface to dielectric coupling at top of stainless-steel casing; 10 ft of 5.56-in.-diameter stainless-steel casing below dielectric coupling	Carbon-steel casing from land surface to top of stainless-steel casing at 354 ft
Backfill Materials (exclusive of filter materials)		Uncontaminated drill cuttings below sump and bentonite above sump	Bentonite in borehole below well; fine sand in transition zone 10 ft above and 3 ft below filter pack; bentonite above transition zone to bottom of surface casing; cement grout between surface casing and borehole wall and between surface casing and well casing	Bentonite below well screen; sand next to well screens; bentonite between sand packs; cement above 70-ft depth
Sump		Stainless-steel casing	5.56-in.-diameter stainless-steel casing 10 ft long	30-ft 5-in.-O.D. stainless steel
Bottom Seal		Bentonite	Bentonite	Bentonite

The most significant modification of planned versus actual activities was the replacement of intermediate-depth well SCIO-3 by the regional aquifer well R-12. In the work plan, SCOI-3 was originally designed to characterize the intermediate-depth perched groundwater zone encountered at a depth of 450 ft by water supply well PM-1 in 1964 (Cooper et al. 1965, 8582). In the hydrogeologic work plan, the core document, and the field implementation plan, R-12 was redesigned to characterize all perched groundwater zones at this location as well as the regional aquifer. R-12 was drilled to a total depth of 886 ft.

The amount of core collected in R-12 was a significant deviation from the amount specified in the hydrogeologic work plan and the core document. In both documents R-12 is designated as a type 3 well (continuous coring). However, because of the slow coring rates along with the associated high costs of collecting core in the previous borehole, R-9, the amount of core planned for collection in R-12 was reduced from 100% to 50% in the field implementation plan. During actual drilling operations, core was not collected from the upper 132.5 ft of R-12 because this interval was previously cored during drilling of SCOI-3. In R-12, poor performance of the 134-mm coring system, particularly in basalt, led to only 10.8% of the hole being cored. Together, R-12 and SCOI-3 provided core for 26.5% of the rock units to a depth of 847 ft in this area.

Steps are being taken to improve the performance of the 134-mm coring system, but it is unlikely that collection of 100% core in any regional well will be achievable within the financial constraints of the well installation program. The need for core should be considered in light of hydrogeologic characterization requirements on a hole-by-hole basis, and only enough core to satisfy sample and characterization needs should be collected. Based on experience from R-12 and R-9, goals for core collection should be clearly established in the field implementation plans for each well. However, the technical team overseeing drilling operations should have the option to modify coring plans based on drilling performance, geologic and hydrologic conditions encountered during drilling, and overall costs of the borehole.

Other modifications to R-12 planned activities were relatively minor. In some cases, ammonium, molybdenum, uranium-236, and nitrogen-15/nitrogen-14 were added to the analytical suite for water samples because of groundwater issues that were identified during the drilling program.

11.0 SUMMARY OF SIGNIFICANT RESULTS

In descending order, geologic units penetrated in R-12 included alluvium, tephras and volcaniclastic sediments of the Cerro Toledo interval, the Otowi Member of the Bandelier Tuff (including the Guaje Pumice Bed), basaltic rocks of the Cerros del Rio volcanic field, old alluvium, the Puye Formation, and basaltic rocks of the Santa Fe Group. The following geologic conditions were encountered.

- Basaltic rocks of the Cerros del Rio volcanic field are 25% thicker in R-12 than in R-9. Also, the basalt sequence in R-12 contains four flow units that are separated by well-defined contacts. These flow units are correlated with four flow units in R-9.
- As in R-9, the lower part of the Puye Formation is composed of a thick sequence of diagenetically altered, reworked tuffaceous sandstone, and conglomerate. Pervasive diagenesis of the tuffaceous sedimentary deposits is expressed by the alteration of volcanic glass to clay minerals.
- The axial facies of the Puye Formation (Totavi Lentil) was expected to occur at the base of the Puye Formation in R-12 based on the lithologic log for nearby supply well PM-1. However, these axial deposits were not present.
- Santa Fe Group sedimentary deposits were expected on top of Miocene basalt in R-12 based on the lithologic log for PM-1. However, sedimentary deposits above the basalt are believed to be an

older part of the Puye Formation that may represent fanglomerate shed from earlier volcanic highlands of the Jemez volcanic field.

- Like R-9, the top of the Santa Fe Group in R-12 consists of basalt. Samples from R-9 indicate that this basalt has a minimum eruption age of 8.45 to 8.63 Ma. This basalt correlates with basalts in the upper part of the Santa Fe Group in PM-1 (Cooper et al. 1965, 8582).

Two saturated groundwater zones were encountered during R-12 drilling operations. The tops of the saturated zones were first encountered at depths of 443 and 805 ft. The upper zone contains perched groundwater, and the lower is believed to be associated with the regional aquifer.

The perched saturated zone occurs in the lower part of basaltic rocks of the Cerros del Rio volcanic field and in the underlying old alluvium. Water was first encountered at 443-ft depth, but rose in the borehole before stabilizing at a depth of 424 ft. Permeability is provided by fractures in basalt in the upper part of the perched zone and by unconsolidated sands and gravels in the lower part. The perching layer consists of clay-rich lake beds.

Groundwater compositions in the perched zone are dominantly a calcium-sodium-bicarbonate-chloride type. However, a sodium-calcium-chloride-sulfate-bicarbonate type groundwater also occurs within the perched zone. Tritium activities range from 208 ± 7 to 255 ± 17 pCi/L, suggesting that a component of the groundwater is less than 50 years old, and is derived from either atmospheric fallout and/or Laboratory discharges. Concentrations of dissolved uranium range from 2.04 ± 0.28 to 2.51 ± 0.34 ppb. Concentrations of nitrate (as nitrogen) range from 0.12 to 5.5 ppm, and concentrations of ammonium (as nitrogen) range from <0.02 to 13.5 ppm. Results of nitrogen-15/nitrogen-14 isotopic analyses (values ranging from +11.3 to +15.2 per mil) are consistent with the derivation of nitrate from sewage sources, possibly including the TA-3 discharge in upper Sandia Canyon. However, nitrogen-15/nitrogen-14 isotopic values of +1.3 per mil for ammonium are not consistent with sewage sources.

The saturated zone at a depth of 805 ft occurs in basalt within the Santa Fe Group. Groundwater in this zone is unconfined, and it is almost certainly associated with the regional aquifer. The elevation of the regional water table in R-12 is 29.4 to 100.4 ft lower than that predicted based on water levels in nearby water supply wells and on existing water-level maps for the regional aquifer. The higher static water levels in nearby water supply wells are probably due to their long screen lengths, which create a composite hydraulic head for each well. The higher static water levels for the supply wells suggest that a higher hydraulic head occurs at deeper levels of the regional aquifer than those penetrated by R-12 and R-9 and that upward gradients may exist in the regional aquifer in this part of the Pajarito Plateau.

The groundwater composition at the top of the regional saturated zone is dominantly a calcium-sodium-bicarbonate type. Tritium activity was measured at 47 ± 2 pCi/L, suggesting the presence of a component of groundwater that is less than 50 years old. The concentration of dissolved uranium, 4.08 ± 0.56 ppb, is slightly elevated relative to most groundwater in the regional aquifer. The concentration of nitrate (as nitrogen) is 0.46 ppm, which is typical of regional groundwater in the Pajarito Plateau area.

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Darril Stafford and Ray Wright were the site safety officers and the radiological control technicians for drilling activities. Trung Nguyen and Doug Barney provided Laboratory oversight for health and safety; Marty Peifer provided Laboratory oversight for radiological controls.

Steve Bolivar, Joe Skalski, and Willanne Winchester provided contract oversight for drilling activities, field support, sample management and curation, and analytical support. Felicia Aguilar, Candi Chroninger, and Robert Trujillo provided data management support. Jenny Harris and Andy Adams supported water sampling activities.

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Appendix A

Lithologic Log

LOS ALAMOS NATIONAL LABORATORY
REGIONAL HYDROGEOLOGIC CHARACTERIZATION PROJECT
ENVIRONMENTAL RESTORATION, CANYONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-12	TA/OU: 72 / 1049	Page 1 of 9
DRILLING COMPANY: Tonto Drilling Co. PHASE 1: March 9,1998-June 9, 1998 Phase 2: October 25, 1999 - March 18, 2000		
DRILLING EQ/METHOD: IR T-4 / Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 6499.6 ft		TOTAL DEPTH = 886' bgs
DRILLER: L. Thoren	GEOLOGY P.I.: Rick Warren	SITE GEOLOGIST: Jon Marin / Mark Everett

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Hydrologic Property (Physprop) and Geochemical (Geochem) Samples (CASA-98-xxxx)	Moisture/Matric Pot. R12-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
0	6500						ALLUVIUM: (0-12.5 ft) Sandy, dry alluvium, predominantly quartz and feldspar grains.		
5	6495					-122 (5.0'-5.1')			
10	6490					-123 (10.0'-10.1')			Qal
15	6485					-124 (15.0'-15.1')	CERRO TOLEDO INTERVAL: (12.5-31.3 ft) Vitric reworked tuff with common tiny pumice to 1 mm and scarce lithics to 1.5 mm. A pumice-rich zone occurs between 27-28' and a clast-rich zone occurs between 28-31.3'.		
20	6480					-125 (19.99'-20.0')			
25	6475				Geochem (-0001)	-126 (24.9'-25.0')			Qct
30	6470					-127 (29.9'-30.0')			
35	6465				Geochem (-0002)	-128 (33.8'-34.0')	OTOWI MEMBER OF BANDELIER TUFF: (31.3-102 ft) Vitric nonwelded tuff with common pumice to 7 mm and less common lithics of intermediate composition.		
40	6460					-129 (39.5'-40.0')			
45	6455					-130 (43.9'-44.0')			
50	6450					-131 (48.9'-49.0')			
55	6445					-132 (54.8'-55.0')			Qbo
60	6440					-133 (59.8'-60.0')			
65	6435					-134 (64.8'-65.0')			
70	6430					-135 (69.8'-70.0')			
75	6425					-136 (74.9'-75.0')			
80	6420					-137 (79.8'-80.0')			
85	6415					-138 (84.8'-85.0')			
90	6410					-139 (89.9'-90.0')			
95	6405					-140 (94.5'-95.0')			
100	6400					-141 (99.0'-100.0')			
							OTOWI MEMBER OF BANDELIER TUFF: (102-112 ft) Variably pumice-rich nonwelded ash flow tuff. Very pumice rich at 104.9 to 105'.		

LOS ALAMOS NATIONAL LABORATORY
REGIONAL HYDROGEOLOGIC CHARACTERIZATION PROJECT
ENVIRONMENTAL RESTORATION, CANYONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-12	TA/OU: 72 / 1049	Page 2 of 9
DRILLING COMPANY: Tonto Drilling Co. PHASE 1: March 9,1998-June 9, 1998 Phase 2: October 25, 1999 - March 18, 2000		
DRILLING EQ/METHOD: IR T-4 / Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 6499.6 ft		TOTAL DEPTH = 886' bgs
DRILLER: L. Thoren	GEOLOGY P.I.: Rick Warren	SITE GEOLOGIST: Jon Marin / Mark Everett

Depth (ft)	Elevation (ft)
105	6395
110	6390
115	6385
120	6380
125	6375
130	6370
135	6365
140	6360
145	6355
150	6350
155	6345
160	6340
165	6335
170	6330
175	6325
180	6320
185	6315

Core Run # (amt.-recov./amt. attemp.) | Core Run | Cuttings Collected

Hydrologic Property (Physprop) and Geochemical (Geochem) Samples (CASA-98-xxxx):
- Geochem (-0003)
- Geochem (-0004)

Moisture/Matric Pot. R12-depth (ft):
- -142 (104.9'-105.0')
- -143 (109.0'-110.0')
- -144 (114.8'-115.0')
- -201 (119.3'-120.0)
- -202 (121.0'-122.0')
- -203 (129.0'-130.0')
- -204 (130.5'-131.0)
- -205 (131.3'-131.5')
- -206 (133.5'-134.0')
- -207 (135.8'-136.0')
- -208 (136.8'-137.0')
- -209 (138.3'-138.5')
- -210 (139.9'-140.0')
- -211 (146.0'-147.0')
- -212 (150.0'-152.0')
- -213 (152.0'-157.0')
- -214 (170.0'-172.0')
- -215 (180.0'-182.0')

Lithology	Graphic Log	Lithologic Symbol
OTOWI MEMBER OF BANDELIER TUFF: (102-112 ft) Variably pumice-rich nonwelded ash flow tuff. Very pumice rich at 104.9 to 105'.		Qbo
GUAJE PUMICE BED: (112-131 ft) Vitric bedded tuff, including laminated vitric ash. Lithics include basalt.		Qbog
PALEOSOL: (131-132.5 ft) Mostly fine sand, with coarse sand-sized argillic pumice and basalt clasts.		
UPPER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (132.5-134.5 ft) Basalt with clay coatings.		Tcb
UPPER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (134.5-162 ft) Slightly vesicular basalt. Rough drilling 142-157'.		
UPPER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (162-184 ft) Massive, nonvesicular to slightly vesicular basalt.		
UPPER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (184-189 ft) Lost circulation zone probably caused by open fractures within basalt.		

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ENVIRONMENTAL RESTORATION, CANYONS FOCUS AREA
BOREHOLE LOG

BOREHOLE ID: R-12	TA/OU: 72 / 1049	Page 3 of 9
DRILLING COMPANY: Tonto Drilling Co.	PHASE 1: March 9,1998-June 9, 1998	Phase 2: October 25, 1999 - March 18, 2000
DRILLING EQ/METHOD: IR T-4 / Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 6499.6 ft		TOTAL DEPTH = 886' bgs
DRILLER: L. Thoren	GEOLOGY P.I.: Rick Warren	SITE GEOLOGIST: Jon Marin / Mark Everett

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Hydrologic Property (Physprop) and Geo-chemical (Geochem) Samples (CASA-98-xxxx)	Moisture/Matric Pot. R12-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
190	6310						UPPER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (189-202 ft) Fractured basalt, poor recovery.		
195	6305								
200	6300					-1 (200.0'-202.0')	UPPER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (202-226 ft) Slightly vesicular basalt. Clay on some chip surfaces.		Tcb
205	6295								
210	6290								
215	6285								
220	6280					-2 (218.0'-222.0')			
225	6275						UPPER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (226-237 ft) Massive, slightly vesicular basalt. Drilling indicates relatively unfractured.		
230	6270					-3 (227.3'-228.0')			
235	6265					-4 (236.6'-237.5')	UPPER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (237-253.5 ft) Massive, nonvesicular basalt.		
240	6260								
245	6255								
250	6250					-5 (248.0'-250.0')			Tcb
255	6245					-6 (256.0'-258.0')	UPPER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (253.5-260.5 ft) Basalt, possibly moist, with clay coatings that are thin at top of interval, thicker towards the bottom.		
260	6240					-8 (261.5'-262.0')			
265	6235					-7 (265.0'-266.0')			
270	6230					-9 (269.0'-270.0')	LOWER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (260.5-262 ft) Moderately vesicular, clay-rich basalt. Clay ranges between 3-30% of chip surfaces.		
275	6225								
280	6220					-10 (277.5'-280.0')	LOWER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (262-342.3 ft) Slightly vesicular basalt. Thin clay near top of interval, clay absent toward bottom. Rough drilling (fractured) 288-293' and 294-316.5'.		
285	6215								
						-11 (287.5'-290.0')			

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DRILLING COMPANY: Tonto Drilling Co.	PHASE 1: March 9,1998-June 9, 1998	Phase 2: October 25, 1999 - March 18, 2000
DRILLING EQ/METHOD: IR T-4 / Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 6499.6 ft		TOTAL DEPTH = 886' bgs
DRILLER: L. Thoren	GEOLOGY P.I.: Rick Warren	SITE GEOLOGIST: Jon Marin / Mark Everett

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Hydrologic Property (Physprop) and Geo-chemical (Geochem) Samples (CASA-98-xxxx)	Moisture/Matric Pot. R12-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
290	6210						LOWER THOLEIITE OF CERROS DEL RIO VOLCANIC FIELD: (262-342.3 ft) Slightly vesicular basalt. Thin clay near top of interval, clay absent toward bottom. Rough drilling (fractured) 288-293' and 294-316.5'.		
295	6205								
300	6200					-12 (297.0'-298.5') -13 (299.2'-300.0')			Tcb
305	6195								
310	6190					-14 (307.8'-310.0')			
315	6185								
320	6180					-15 (317.8'-320.0')			
325	6175								
330	6170					-16 (327.0'-330.0')			
335	6165								
340	6160					-17 (338.0'-340.0')			
345	6155					-18 (342.95'-343.0') -19 (345.6'-346.0')	UPPER ALKALIC BASALT OF CERROS DEL RIO VOLCANIC FIELD: (342.3-351 ft) Moderately vesicular basalt with some clay.		
350	6150					-20 (348.3'-349.0')			
355	6145					-21 (351.9'-352.0')	UPPER ALKALIC BASALT OF CERROS DEL RIO VOLCANIC FIELD: (351-405 ft) Slightly vesicular basalt at the top of interval, with thin clay zone, massive basalt at the base.		Tcb
360	6140					-22 (358.0'-358.5')			
365	6135								
370	6130					-23 (369.2'-370.0')			
375	6125					-24 (374.5'-375.5')			
380	6120					-37 (379.2'-380.0')			
385	6115					-38 (386.8'-388.0')			

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DRILLING COMPANY: Tonto Drilling Co.	PHASE 1: March 9,1998-June 9, 1998	Phase 2: October 25, 1999 - March 18, 2000
DRILLING EQ/METHOD: IR T-4 / Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 6499.6 ft		TOTAL DEPTH = 886' bgs
DRILLER: L. Thoren	GEOLOGY P.I.: Rick Warren	SITE GEOLOGIST: Jon Marin / Mark Everett

Columns: Depth (ft) | Elevation (ft) | Core Run # (amt.-recov./amt. attemp.) | Core Run | Cuttings Collected | Hydrologic Property (Physprop) and Geochemical (Geochem) Samples (CASA-98-xxxx) | Moisture/Matric Pot. R12-depth (ft) | Lithology | Graphic Log | Lithologic Symbol

Depth (ft)	Elevation (ft)
390	6110
395	6105
400	6100
405	6095
410	6090
415	6085
420	6080
425	6075
430	6070
435	6065
440	6060
445	6055
450	6050
455	6045
460	6040
465	6035
470	6030
475	6025
480	6020
485	6015

Core Run # (amt.-recov./amt. attemp.):
- C-1(0/5.0)
- C-4(1.3/1.5)
- C-2(0.2/1.0)
- C-3(1.0/1.0)
- C-5(1.0/1.0)
- C-6(0.7/1.5)
- C-7(0.7/1.0)
- C-8(2.4/2.7)
- C-9(1.1/1.0)
- C-10(0.2/1.3)

Hydrologic Property and Geochemical Samples:
- Geotech (-0013)
- Geotech (-0014)
- Geochem (-0006)
- Geotech (-0007)
- Geotech (-0021)
- Geotech (-0022)

Moisture/Matric Pot. R12-depth (ft):
- -39 (395.3'-397.0')
- -40 (400.0'-401.0')
- -41 (406.0'-408.0')
- -216 (420.5'-420.8')
- -217 (421.2'-421.33')
- -42 (438.0'-442.0')
- -44 (442.0'-444.0')
- -43 (444.0'-449.0')
- -45 (458.6'-459.0')

Lithology:

UPPER ALKALIC BASALT OF CERROS DEL RIO VOLCANIC FIELD: (351-405 ft) Slightly vesicular basalt at the top of interval, with thin clay zone, massive basalt at the base.

UPPER ALKALIC BASALT OF CERROS DEL RIO VOLCANIC FIELD: (405-411 ft) Moist basalt. Some clay present.

PALEOSOL: (411-419.2 ft) Drilling performance indicates entire interval is similar to 0.1' of massive clay recovered. Clay probably of lacustrine origin or is a soil.

LOWER ALKALIC BASALT OF CERROS DEL RIO VOLCANIC FIELD: (419.2-425 ft) Moderately vesicular basaltic breccia, with local clay in fractures and vesicles. Moist near top.

LOWER ALKALIC BASALT OF CERROS DEL RIO VOLCANIC FIELD: (425-450 ft) Dry, massive basalt with minor clay on fractures. First perched water at 443', static at 424.36' bgs.

LOWER ALKALIC BASALT OF CERROS DEL RIO VOLCANIC FIELD: (450-488.2 ft) Saturated, massive basalt. Slightly vesicular near base, with some calcite infilling. Fractured, based on drilling performance.

LOWER ALKALIC BASALT OF CERROS DEL RIO VOLCANIC FIELD: (488.2-488.9 ft) Moist basaltic breccia, with lenses of underlying tephra.

Lithologic Symbol: Tcb (upper basalt interval); Tcb (lower basalt interval)

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DRILLING COMPANY: Tonto Drilling Co. PHASE 1: March 9,1998-June 9, 1998 Phase 2: October 25, 1999 - March 18, 2000

DRILLING EQ/METHOD: IR T-4 / Foremost DR24 SAMPLING EQ/METHOD: Wireline core barrel sampling

GROUND ELEVATION: 6499.6 ft TOTAL DEPTH = 886' bgs

DRILLER: L. Thoren GEOLOGY P.I.: Rick Warren SITE GEOLOGIST: Jon Marin / Mark Everett

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Hydrologic Property (Physprop) and Geo-chemical (Geochem) Samples (CASA-98-xxxx)	Moisture/Matric Pot. R12-depth (ft)
490	6010	C-11(1.3/0.4) C-12(2.2/1.9) C-13(1.5/2.0) C-14(1.4/2.0)	Geotech (-0023) Geotech (-0024)	
495	6005			
500	6000			
505	5995			
510	5990	C-14.5(2.7/2.7) C-15(2.8/4.64)	Hydrology (-0029) Geotech (-0026) Geotech (-0027)	
515	5985	C-16(1.9/3.2)		
520	5980	C-17(0.1/1.0)	Geochem (-0008)	-33 (520.4'-520.5')
525	5975	C-18(4.05/4.05)	Geotech (-0030) Hydrology (-0031)	-34 (523.7'-523.8')
530	5970			
535	5965			
540	5960			
545	5955			
550	5950			
555	5945			-35 (553.5'-555.0')
560	5940		Geochem (-0032 & 0034)	-36 (559.0'-560.0')
565	5935			-49 (564.0'-565.0')
570	5930		Geochem (-0033)	-50 (569.0'-570.0')
575	5925			-51 (574.0'-575.0')
580	5920			-52 (578.85'-580.0')

Lithology

LOWER ALKALIC BASALT OF CERROS DEL RIO VOLCANIC FIELD: (488.2-488.9 ft) Moist basaltic breccia, with lenses of underlying tephra.

LOWER ALKALIC BASALT OF CERROS DEL RIO VOLCANIC FIELD: (488.9-491.6 ft) Basaltic tephra; fine- to coarse-grained basaltic ash, glassy, moist. Fine ash forms discontinuous lenses.

OLD ALLUVIUM: (491.6-495 ft) Fine-grained sand, some clasts of intermediate volcanics.

OLD ALLUVIUM: (495-509 ft) Sandy gravel of quartzite, granite, gneiss, and intermediate volcanics to 37 mm, all well rounded. Axial deposit of ancestral Rio Grande.

OLD ALLUVIUM: (509-519.1 ft) Fine to medium sand, silt- and clay-rich, saturated, cohesive, with some subrounded clasts of basalt to 10 mm.

OLD ALLUVIUM: (519.1-535.5 ft) Micaceous claystone, dry below 520'. Some zones contain fine sand. Laminae suggest lake deposition.

OLD ALLUVIUM: (535.5-545 ft) Gravelly sand with clasts that include devitrified dacitic lava (Tschicoma Formation), and somewhat lesser moderately vesicular, argillic to unaltered basalt.

PUYE FORMATION: (545-560 ft) Conglomerate with sandy matrix, abundant moderately-well-rounded clasts to 15 mm, and small vitric pumice. Clasts are dominately devitrified lava with lesser vitric lava of intermediate composition.

PUYE FORMATION: (560-584.3 ft) Pebbly sand with common subrounded-to-angular clasts to 13 mm, and small vitric pumice.

Lithologic Symbol: Ta (approx. 510 ft), Ta (approx. 530 ft), Tp (approx. 575 ft)

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DRILLING COMPANY: Tonto Drilling Co. PHASE 1: March 9,1998-June 9, 1998 Phase 2: October 25, 1999 - March 18, 2000

DRILLING EQ/METHOD: IR T-4 / Foremost DR24 | SAMPLING EQ/METHOD: Wireline core barrel sampling

GROUND ELEVATION: 6499.6 ft | TOTAL DEPTH = 886' bgs

DRILLER: L. Thoren | GEOLOGY P.I.: Rick Warren | SITE GEOLOGIST: Jon Marin / Mark Everett

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Hydrologic Property (Physprop) and Geo-chemical (Geochem) Samples (CASA-98-xxxx)	Moisture/Matric Pot. R12-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
580	5920						PUYE FORMATION: (560-584.3 ft) Pebbly sand with common subrounded-to-angular clasts to 13 mm, and small vitric pumice.		
585	5915					-53 (584.3'-585.0')			
590	5910					-54 (589.3'-590.0')	PUYE FORMATION: (584.3-628.7 ft) Slightly pumiceous gravel with sandy matrix, abundant subangular clasts to 14 mm, and some vitric pumice. Near base, clasts to 10 mm.		
595	5905					-55 (594.3'-595.0')			
600	5900					-56 (599.04'-600.0')			
605	5895					-57 (604.13'-605.0')			
610	5890					-58 (609.45'-610.0')			
615	5885					-59 (614.0'-615.0')			
620	5880					-60 (618.7'-620.0')			
625	5875					-61 (624.2'-625.0')			Tp
630	5870					-62 (628.75'-630.0')	PUYE FORMATION: (628.7-637.3 ft) Gravelly sand with common, moderately well rounded clasts, and lesser vitric pumice.		
635	5865					-63 (633.75'-635.0')			
640	5860					-64 (639.0'-640.0')	PUYE FORMATION: (637.3-666 ft) Slightly pumiceous gravel with sandy matrix and abundant subangular clasts to 15 mm, and minor vitric pumice.		
645	5855					-65 (643.9'-645.0')			
650	5850					-66 (648.9'-650.0')			
655	5845					-67 (653.75'-655.0')			
660	5840					-68 (658.9'-660.0')			
665	5835					-69 (663.67'-665.0')	PUYE FORMATION: (666-712.5 ft) Moderately-calcareous, argillic, pebbly sandstone. Common clasts are devitrified intermediate composition lava. Rare to common pumice is vitric near top, argillic below.		
670	5830								
675	5825					-70 (672.2'-673.0')			Tp
680	5820								

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DRILLING COMPANY: Tonto Drilling Co. PHASE 1: March 9,1998-June 9, 1998 Phase 2: October 25, 1999 - March 18, 2000		
DRILLING EQ/METHOD: IR T-4 / Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 6499.6 ft		TOTAL DEPTH = 886' bgs
DRILLER: L. Thoren	GEOLOGY P.I.: Rick Warren	SITE GEOLOGIST: Jon Marin / Mark Everett

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Hydrologic Property (Physprop) and Geo-chemical (Geochem) Samples (CASA-98-xxxx)	Moisture/Matric Pot. R12-depth (ft)
680	5820			
685	5815			
690	5810			
695	5805			
700	5800			
705	5795			
710	5790			-71 (709.2'-710.0')
715	5785	C-19(4.0/5.0)		-72 (713.9'-715.0')
720	5780	C-20(4.9/5.0)	Geotech (-0041)	-224 (719.78'-720.0')
725	5775	C-21(4.6/5.0)	Geotech (-0048)	-223 (725.45'-725.65')
730	5770	C-22(2.2/5.0)	Geotech (-0049)	-222 (730.3'-730.6')
735	5765	C-23(0.2/5.0)		-221 (733.0'-733.2')
740	5760	C-24(0.3/0.3) C-25(4.7/4.7)		
745	5755	C-26(5.1/5.3)	Geotech (-0047)	-122 (742.1'-742.2') -123 (745.8'-746.0)
750	5750	C-27(4.7/4.7)	Geotech (-0043)	-220 (750.7'-751.1')
755	5745	C-28(5.0/5.0)	Geotech (-0044)	-5201A (755.9'-756.0')
760	5740	C-29(5.0/5.0)		-273 (760.85'-761.0')
765	5735	C-30(5.0/5.0)	Geotech (-0046)	-274 (765.7'-766.0')
770	5730	C-31(4.45/5.0)	Geotech (-0042)	-275 (770.8'-771.0')
775	5725	C-32(0.8/0.8) C-33(2.7/2.7)	Geotech (-0039) Geotech (-0040)	-276 (775.25'-775.45')
780	5720			-277 (779.2'-779.5')

Lithology (Lithologic Symbol: Tp)

PUYE FORMATION: (666-712.5 ft) Moderately calcareous, argillic, pebbly sandstone. Common clasts are devitrified intermediate composition lava. Rare to common pumice is vitric near top, argillic below.

PUYE FORMATION: (712.5-726.4 ft) Argillic, highly pumiceous sandstone. Clasts of devitrified lava are rare. Base of interval (726.1-726.4') is an argillic pumice fall.

PUYE FORMATION: (726.4-746.4 ft) A series of reworked generally argillic pumiceous deposits; upward fining cycles, each grading from sandstone at the top to conglomerate at the base. Base of interval (746.1-746.4') is an argillic pumice fall.

PUYE FORMATION: (746.4-764 ft) A series of reworked, generally argillic pumiceous deposits; upward fining cycles, each grading from sandstone at the top to conglomerate at the base.

PUYE FORMATION: (764-784 ft) Pumiceous sandstone with common argillic pumice, generally to 6 mm, rarely to 28 mm. Clasts of devitrified lava up to 3.5 mm are scarce near top, and up to 12 mm are common near base.

Tp

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DRILLING COMPANY: Tonto Drilling Co. PHASE 1: March 9,1998-June 9, 1998 Phase 2: October 25, 1999 - March 18, 2000		
DRILLING EQ/METHOD: IR T-4 / Foremost DR24		SAMPLING EQ/METHOD: Wireline core barrel sampling
GROUND ELEVATION: 6499.6 ft		TOTAL DEPTH = 886' bgs
DRILLER: L. Thoren	GEOLOGY P.I.: Rick Warren	SITE GEOLOGIST: Jon Marin / Mark Everett

Depth (ft)	Elevation (ft)	Core Run # (amt.-recov./amt. attemp.)	Core Run	Cuttings Collected	Hydrologic Property (Physprop) and Geo-chemical (Geochem) Samples (CASA-98-xxxx)	Moisture/Matric Pot. R12-depth (ft)	Lithology	Graphic Log	Lithologic Symbol
780	5720						PUYE FORMATION: (764-784 ft) Pumiceous sandstone with common argillic pumice, generally to 6 mm, rarely to 28 mm. Clasts of devitrified lava up to 3.5 mm are scarce near top, and up to 12 mm are common near base.		
785	5715						SANTA FE GROUP BASALT: (784-830 ft) Slightly scoriaceous, coarse-grained basalt with very irregular vesicles to 1-mm length. Saturated zone encountered at 804.84'; unconfined.		
790	5710								
795	5705				Geotech (-0057)				
800	5700				Geotech (-0056)				
805	5695					-124 (804.66'-805.0')			
810	5690					-125 (809.64'-810.0')			
815	5685				Geotech (-0055 & -0054)				
820	5680								
825	5675								
830	5670						SANTA FE GROUP BASALT: (830-886 ft) Slightly vesicular, coarse-grained basalt with round to slightly elongate vesicles to 6 mm, some coated with white clay, which also occurs as cuttings to 5 mm.		Tsfb
835	5665								
840	5660								
845	5655								
850	5650								
855	5645								
860	5640								
865	5635								
870	5630								
875	5625								
880	5620								
885	5615								

Appendix B

Descriptions of Geologic Samples

Sample No.	Description*	Discussion
R12-15D	B	Cuttings from 15.0 ft depth in drill hole R12 are moderate brown vitric nonwelded tuff with common orange-pink pumice to 1 mm. Lithics and felsics, both to 1.5 mm, are scarce in friable but coherent rock fragments to 20 mm. Size fraction >2 mm, retained on 10 mesh sieve, is mostly silky white vitric pumice to 19 mm. No mafics were observed in these pumices. Lithics to 10 mm are mostly angular, but include rounded fragments. Two 9 mm fragments are noncalcareous, devitrified nonwelded tuff with common to abundant quartz and chatoyant sanidine; one is pale grayish orange pink with moderate yellowish brown hematitic staining, and the other is grayish orange pink with undeformed pumice to 3 mm.
R12-15D	T	Thin section contains predominant clasts of vitric pyroclasts, ranging from aphyric to porphyritic with phenocrysts of quartz, sanidine, and sodic plagioclase. Most of these pyroclasts are reworked vesicular pumice fragments. One clast consists of an intermediate lava with abundant quartz-plagioclase-oxyamphibole phenocrysts plus single-mineral clasts of olivine, biotite, and clinopyroxene within a clay-rich soil that also contains a fossil plant marked by oxide replacements of stem structure, a detrital fragment of exotic dark-green amphibole, and a vitric pyroclast with a biotite phenocryst.
R12-85D	B	Cuttings from 84.8 to 85.0 ft depths in drill hole R12 are pinkish gray vitric nonwelded tuff with common pinkish gray pumice to 7 mm. Size fraction >0.5 mm, retained on 35 mesh sieve, is mostly pumice to 10 mm dominant over lithics, mostly medium dark gray devitrified lava to 7 mm.
R12-85D10	B	Sample from 84.8 to 85.0 ft depths in drill hole R12 consists of ultrasonically cleaned cuttings >2 mm that are retained on a 10 mesh sieve. Fragments are primarily light gray to pinkish gray vitric pumice to 8 mm with scarce to rare feldspar. About 15% of fragments are lithics of devitrified lava to 13 mm.
R12-85D10PU	B	Sample from 84.8 to 85.0 ft depths in drill hole R12 consists of pumices hand-picked from ultrasonically cleaned cuttings >2 mm that are retained on a 10 mesh sieve. Fragments are light gray to pinkish gray vitric pumice to 8 mm with scarce to rare feldspar.
R12-85D10PU	T	Thin section consists almost entirely of vitric nonwelded tuff with elongate to equant vesicles. Phenocrysts (~2 mm) consist of sanidine, quartz, and plagioclase with small and rare amphibole. Total phenocryst abundance estimated at ~8% with sanidine>quartz>>plagioclase. Thin section includes one clast of devitrified tuff with vapor-phase feldspar and sanidine phenocrysts.
R12-105D	B	Cuttings from 104.9 to 105.0 ft depths in drill hole R12 are pinkish gray vitric pumice to 8 mm without matrix. Pumices contain scarce felsics and rare, tiny mafics, which include dark green clinopyroxene prisms to 0.5 mm and smaller, black, equant olivine. Scarce lithics include conspicuous dark gray basalt to 4 mm , to 8 mm in >2 mm size fraction retained on 10 mesh sieve.
R12-105D10	B	Sample from 104.9 to 105.0 ft depths in drill hole R12 consists of ultrasonically cleaned cuttings >2 mm that are retained on a 10 mesh sieve. Fragments are almost entirely very light gray vitric pumice to 7 mm with scarce feldspar. A few percent of fragments are lithics to 6 mm, mostly dark gray devitrified lava with common feldspar to 2 mm and common, dark green, equant clinopyroxene to 0.6 mm.
R12-105D10PU	B	Sample from 104.9 to 105.0 ft depths in drill hole R12 consists of pumices hand-picked from ultrasonically cleaned cuttings >2 mm that are retained on a 10 mesh sieve. Fragments are very light gray vitric pumice to 7 mm with scarce feldspar.
R12-105D10PU	T	Thin section consists entirely of fragments of vitric nonwelded tuff with elongate to equant vesicles. Phenocrysts (1 mm to 2 mm) consist of sanidine and quartz with smaller (0.3–0.1 mm) grains of sodic plagioclase and rare amphibole. Amphibole is more abundant than in the tuff sample at 85 ft depth; amphibole is unoxidized and pleochroic. Total phenocryst abundance estimated at ~8% with sanidine>quartz>>plagioclase>amphibole.

Sample No.	Description*	Discussion
R12-120D	B	Cuttings from 119.3 to 120 ft depths in drill hole R12 are light gray vitric bedded tuff. Some fragments show 2 mm laminae of light gray and pinkish gray vitric ash.
R12-120D10	B	Sample from 119.3 to 120 ft depths in drill hole R12 consists of ultrasonically cleaned cuttings >2 mm that are retained on a 10 mesh sieve. Fragments are primarily very light gray vitric pumice to 6 mm with scarce to rare black vitreous mafics. About 5% of fragments are lithics, which include hydrothermally altered lava to 7 mm with chalky white feldspar, dark gray scoriaceous andesite to 9 mm with tiny black pyroxene, and white, coarse sandstone.
R12-120D10PU	B	Sample from 119.3 to 120 ft depths in drill hole R12 consists of pumices hand-picked from ultrasonically cleaned cuttings >2 mm that are retained on a 10 mesh sieve. Fragments are very light gray vitric pumice to 6 mm with scarce to rare black vitreous mafics.
R12-120D10PU	T	Thin section consists almost entirely of vitric pumice fragments with elongate to equant vesicles. Phenocrysts (0.5 to 1 mm) consist of sanidine and quartz with smaller (~0.3 mm) plagioclase and amphibole grains. Phenocryst abundance is estimated at ~7% with sanidine>quartz>>plagioclase>amphibole. One pumice fragment differs in smaller phenocrysts, dominated by quartz grains with melt or fluid inclusions, sanidine, plagioclase, anhedral amphibole, and biotite with some exotic plagioclase inclusions (mottled extinction with abundant dark but unoxidized biotite inclusions – possible metamorphic origin).
R12-131.5D	B	Cuttings from 131.3 to 131.5 ft depths in drill hole R12 are moderate yellowish brown fine sand. Size fraction >0.5 mm, retained on 35 mesh sieve, is mostly coarse sand, with a few larger fragments of dark gray basalt to 6 mm, probably from underlying basalt; coarse sand is mostly white, argillic pumice.
R12-138.5D	B	Ultrasonically cleaned cuttings from 138.3 to 138.5 ft depths in drill hole R12 are fragments of dark gray basalt to 18 mm with scattered ovoid vesicles, generally 2 to 4 mm long, common plagioclase to 2.5 mm, and scarce to rare olivine to 1 mm.
R12-138.5D	T	Thin section consists entirely of porphyritic to glomeroporphyritic olivine basalt. Glomerocrysts of up to ~10 grains are principally of plagioclase laths with subhedral to anhedral olivine. Groundmass is intergranular to intersertal. Olivine phenocrysts are 0.15–0.75 mm and ~3% of the sample; plagioclase phenocrysts are as large as 1.5 mm but grade into groundmass feldspar size at ~0.15 mm. Maximum symmetrical extinction angles on albite twins are ~30° (~An55). Groundmass includes feldspar, olivine, pyroxene, skeletal cruciform magnetite, and ilmenite.
R12-228D	B	Ultrasonically cleaned cuttings from 227.3 to 228 ft depths in drill hole R12 are fragments of slightly vesicular, medium dark gray basalt to 26 mm with scattered ovoid vesicles to 6 mm long, and common light olive olivine to 1.5 mm, occasionally to 4 mm.
R12-228D	T	Thin section consists entirely of porphyritic olivine basalt. Glomerocrysts of olivine plus plagioclase are rare. Groundmass is intergranular to devitrified intersertal. Olivine phenocrysts are 0.2–1.2 mm and ~1% of the sample; plagioclase phenocrysts are as large as 0.5 mm, which is only slightly larger than the typical groundmass feldspar size range. Maximum symmetrical extinction angles on phenocryst albite twins are ~25° (~An45). Groundmass includes feldspar (maximum symmetrical extinction on albite twins of ~30° indicates compositions as calcic as ~An55), olivine, pyroxene, skeletal to euhedral magnetite, and ilmenite.
R12-270D	B	Ultrasonically cleaned cuttings from 269 to 270 ft depths in drill hole R12 are fragments of dark gray basalt to 19 mm with scattered round vesicles to 9 mm diameter, and common green olivine to 1.8 mm. Very light brown clay occurs in scarce to rare massive fragments to 3 mm thick, and very thinly and discontinuously on fragment surfaces within the size fraction >0.5 mm, retained on 35 mesh sieve.

Sample No.	Description*	Discussion
R12-270D	T	Thin section consists entirely of porphyritic to aphyric vesicular olivine basalt. Groundmass is intergranular. Olivine phenocrysts are 0.2–0.8 mm and ~3% of the sample; plagioclase phenocrysts are as large as 1 mm in rare clots. Maximum symmetrical extinction angles on phenocryst albite twins are ~33° (~An60). Groundmass includes feldspar (maximum symmetrical extinction on albite twins similar to that in phenocrysts, indicating ~An60), olivine, pyroxene, skeletal magnetite, and ilmenite. Iddingsite replaces much of the groundmass olivine.
R12-380D	B	Ultrasonically cleaned cuttings from 379.2 to 380 ft depths in drill hole R12 are fragments of medium dark gray, coarse grained, massive basalt to 16 mm with rare irregular vesicles to 3 mm and common light green olivine to 3 mm.
R12-380D	T	Thin section consists of varied porphyritic non-vesicular to vesicular olivine basalt. Groundmass is intergranular. Olivine phenocrysts are 0.2–1.0 mm and ~3% of the sample; plagioclase phenocrysts are as large as 0.8 mm and are strongly sieved. Groundmass includes feldspar (maximum symmetrical extinction on albite twins ~16°, ~An35), abundant olivine, pyroxene, relatively large euhedral magnetite up to 0.15 mm, and ilmenite.
R12-442D	B	Ultrasonically cleaned cuttings from 438 to 442 ft depths in drill hole R12 are fragments of medium dark gray, massive basalt to 20 mm.
R12-442D	T	Thin section consists of altered to unaltered porphyritic olivine basalt. Groundmass intergranular to trachytic. Olivine phenocrysts are 0.2–1.2 mm and ~2–3% of the sample; there are no plagioclase phenocrysts. Groundmass includes 0.5 mm feldspar laths with maximum symmetrical extinction on albite twins ~32° (~An60), olivine, pyroxene, euhedral magnetite, and ilmenite needles. About 40% of the fragments in the thin section show extensive alteration of olivine to iddingsite.
R12-520.5	B	Core from 520.4 to 520.5 ft depths in drill hole R12 is pale yellowish brown, very well indurated micaceous claystone.
R12-555D	B	Cuttings from 553.5 to 555 ft depths in drill hole R12 are yellowish brown gravel with abundant, generally subrounded lithics to 15 mm. Some fragments of consolidated matrix occur, and they contain small white vitric pumice. Description for lithics is found in description for sample R12-555D10.
R12-555D10	B	Cuttings from 553.5 to 555 ft depths in drill hole R12 were repeatedly collected on a 10-mesh sieve during wet sieving and then ultrasonically cleaned. Most of the matrix that probably is the dominant constituent is much finer than this >2-mm size fraction. These cuttings, to 13 mm, are mostly subrounded to subangular lithics of devitrified lava, most with conspicuous feldspar, some with hornblende and/or biotite, and one with a single 2 mm clinopyroxene. Lithics also include very light gray pumiceous to brownish black massive vitric lava. Several fragments of grayish orange, well cemented but noncalcareous matrix with white vitric pumice are retained in this size fraction.
R12-555D10	T	Thin section contains 18 fragments with variable lithology. Lithologies are all intermediate-composition lavas except for two fragments of arkosic sandstone containing small fragments of plagioclase-clinopyroxene lava, feldspars, clinopyroxene, and wormy quartz in a clay matrix. The varieties of intermediate-composition lavas include 5 quartz-bearing fragments and 11 quartz-free fragments. In the intermediate lavas overall clinopyroxene is more abundant than orthopyroxene; 6 of the fragments contain amphibole or biotite. One of the intermediate lavas is a crystal-rich plagioclase-clinopyroxene-orthopyroxene vitric pumice.
R12-555D32	B	Cuttings from 553.5 to 555 ft depths in drill hole R12 initially passed a 10-mesh sieve and then were repeatedly collected on a 32-mesh sieve during wet sieving, followed by ultrasonic cleaning. Most of the matrix that probably is the dominant constituent is much finer than this 0.5- to 2-mm size fraction.

Sample No.	Description*	Discussion
R12-565D	B	Cuttings from 564 to 565 ft depths in drill hole R12 are pale yellowish brown sand with common subrounded to subangular lithics to 13 mm. Many fragments of consolidated matrix occur, and they contain small white vitric pumice, some with small green prisms of clinopyroxene. Description for lithics is found in description for sample R12-565D10.
R12-565D10	B	Cuttings from 564 to 565 ft depths in drill hole R12 were repeatedly collected on a 10-mesh sieve during wet sieving and then ultrasonically cleaned. Most of the matrix that probably is the dominant constituent is much finer than this >2-mm size fraction. These cuttings, to 18 mm, are mostly subrounded to subangular lithics of devitrified lava, most with conspicuous feldspar, and some with hornblende, biotite, clinopyroxene, and/or quartz. Lithics also include medium light gray, pumiceous to massive vitric lava with black hornblende and biotite, and green clinopyroxene.
R12-565D10	T	Thin section contains 17 fragments with variable lithology. Lithologies are all intermediate-composition lavas. The varieties of intermediate-composition lavas include 1 quartz-bearing fragments and 16 quartz-free fragments. In the intermediate lavas overall clinopyroxene is more abundant than orthopyroxene; 5 of the fragments contain amphibole and/or biotite.
R12-565D35	B	Cuttings from 564 to 565 ft depths in drill hole R12 initially passed a 10-mesh sieve and then were repeatedly collected on a 35-mesh sieve during wet sieving, followed by ultrasonic cleaning. Most of the matrix that probably is the dominant constituent is much finer than this 0.5- to 2-mm size fraction.
R12-605D	B	Cuttings from 604.1 to 605 ft depths in drill hole R12 are brownish gray gravel with very abundant lithics to 14 mm and much less abundant white vitric pumice with common orthopyroxene. Description for lithics is found in description for sample R12-605D10.
R12-605D10	B	Cuttings from 604.1 to 605 ft depths in drill hole R12 were repeatedly collected on a 10-mesh sieve during wet sieving and then ultrasonically cleaned. Most of the matrix that probably is the dominant constituent is much finer than this >2-mm size fraction. These cuttings, to 14 mm, are mostly subangular to subrounded lithics of devitrified lava, most with conspicuous feldspar, and some with black hornblende to 2 mm, bronze to black biotite to 2 mm, dark green clinopyroxene, dark brown orthopyroxene, and/or quartz. Lithics also include light gray pumiceous to medium dark gray massive vitric lava. The largest lithic observed is a coarse-grained, flinty quartzite.
R12-605D10	T	Thin section contains 18 fragments with variable lithology. Lithologies are all intermediate-composition lavas. The varieties of intermediate-composition lavas include 9 quartz-bearing fragments and 9 quartz-free fragments. In the intermediate lavas overall clinopyroxene and orthopyroxene are approximately equal in abundance; 5 of the fragments contain amphibole and/or biotite. One of the quartz-free fragments is a vitric pumice containing plagioclase, clinopyroxene, and amphibole.
R12-605D35	B	Cuttings from 604.1 to 605 ft depths in drill hole R12 initially passed a 10-mesh sieve and then were repeatedly collected on a 35-mesh sieve during wet sieving, followed by ultrasonic cleaning. Most of the matrix that probably is the dominant constituent is much finer than this 0.5- to 2-mm size fraction.
R12-630D	B	Cuttings from 628.75 to 630 ft depths in drill hole R12 are yellowish brown sand with common subrounded lithics to 12 mm and less abundant white vitric pumice with black biotite. Description for lithics is found in description for sample R12-630D10.
R12-630D10	B	Cuttings from 628.75 to 630 ft depths in drill hole R12 were repeatedly collected on a 10-mesh sieve during wet sieving and then ultrasonically cleaned. Most of the matrix that probably is the dominant constituent is much finer than this >2-mm size fraction. These cuttings, to 11 mm, are mostly subrounded to subangular lithics of devitrified to vitric lava with conspicuous feldspar and quartz, and conspicuous biotite to 2 mm and green prisms of clinopyroxene to 3 mm. Cuttings also include white vitric pumice to 3 mm.

Sample No.	Description*	Discussion
R12-630D10	T	Thin section contains 15 fragments with variable lithology. Lithologies are all intermediate-composition lavas with the exception of one basalt. The varieties of intermediate-composition lavas include 5 quartz-bearing fragments and 9 quartz-free fragments. In the intermediate lavas overall clinopyroxene and orthopyroxene are approximately equal in abundance but relatively rare; 5 of the fragments contain amphibole and/or biotite. One of the quartz-free fragments is an aphyric vitric pumice.
R12-630D35	B	Cuttings from 628.75 to 630 ft depths in drill hole R12 initially passed a 10-mesh sieve and then were repeatedly collected on a 35-mesh sieve during wet sieving, followed by ultrasonic cleaning. Most of the matrix that probably is the dominant constituent is much finer than this 0.5- to 2-mm size fraction.
R12-655D	B	Cuttings from 653.75 to 655 ft depths in drill hole R12 are pale yellowish brown gravel with abundant lithics to 11 mm and minor white vitric pumice. Description for lithics is found in description for sample R12-655D10.
R12-655D10	B	Cuttings from 653.75 to 655 ft depths in drill hole R12 were repeatedly collected on a 10-mesh sieve during wet sieving and then ultrasonically cleaned. Most of the matrix that probably is the dominant constituent is much finer than this >2-mm size fraction. These cuttings, to 11 mm, are mostly subrounded to subangular lithics of devitrified lava with conspicuous feldspar and some quartz, and scarce to common mafics, mostly bronze to black biotite. Lithics also include light gray pumiceous to dark brownish gray massive vitric lava.
R12-655D10	T	Thin section contains 16 fragments with variable lithology. Lithologies are all intermediate-composition lavas. The varieties of intermediate-composition lavas include 1 quartz-bearing fragment and 15 quartz-free fragments. In the intermediate lavas overall clinopyroxene and orthopyroxene are approximately equal in abundance; 4 of the fragments contain amphibole or biotite.
R12-655D35	B	Cuttings from 653.75 to 655 ft depths in drill hole R12 initially passed a 10-mesh sieve and then were repeatedly collected on a 35-mesh sieve during wet sieving, followed by ultrasonic cleaning. Most of the matrix that probably is the dominant constituent is much finer than this 0.5- to 2-mm size fraction.
R12-710D	B	Cuttings from 709.2 to 710 ft depths in drill hole R12 are yellowish brown argillic, pebbly sand with common lithics to 10 mm and rare white argillic pumice with biotite to 8 mm. Description for lithics is found in description for sample R12-630D10.
R12-710D10	B	Cuttings from 709.2 to 710 ft depths in drill hole R12 were repeatedly collected on a 10-mesh sieve during wet sieving and then ultrasonically cleaned. Most of the matrix that probably is the dominant constituent is much finer than this >2-mm size fraction. These cuttings, to 9 mm, are mostly subangular lithics of devitrified lava with common feldspar, abundant dark green clinopyroxene and dark brown orthopyroxene, and much lesser biotite and hornblende. Lithics also include minor light gray argillic pumiceous lava.
R12-710D10	T	Thin section contains 14 fragments with variable lithology. Lithologies are all intermediate-composition lavas with the exception of one basalt and one sandstone. The varieties of intermediate-composition lavas include no quartz-bearing fragments and 12 quartz-free fragments. In the intermediate lavas overall clinopyroxene is more abundant than orthopyroxene; 4 of the fragments contain amphibole and/or biotite.
R12-710D35	B	Cuttings from 709.2 to 710 ft depths in drill hole R12 initially passed a 10-mesh sieve and then were repeatedly collected on a 35-mesh sieve during wet sieving, followed by ultrasonic cleaning. Most of the matrix that probably is the dominant constituent is much finer than this 0.5- to 2-mm size fraction.

Sample No.	Description*	Discussion
R12-720	B	Core from 719.78 to 720 ft depths in drill hole R12 is pale yellowish brown, argillic, highly pumiceous sandstone with very abundant light greenish white pumice to 13/3 mm, abundant mafics of conspicuous green clinopyroxene and dark brown, partly altered orthopyroxene, and rare lithics to 2 mm.
R12-720	T	Thin section is of a clay-rich altered ash. Unaltered grains include fragments of amphibole-bearing dacite, clinopyroxene, and olivine (olivine crystals as large as 1 mm). The clay matrix is massive with little evidence or remnant pyroclast texture.
R12-726.4	B	Core from 726.2 to 726.4 ft depths in drill hole R12 is light greenish gray argillic pumice fall, with pumices to 5 mm and abundant black mafics, mostly biotite to 1 mm, and lesser hornblende.
R12-726.4	T	Thin section is of a clay-rich altered ash. Unaltered grains are rare except for yellow-brown amphibole of 0.5 mm. The clay matrix is massive with little evidence or remnant pyroclast texture.
R12-730.6	B	Core from 730.3 to 730.6 ft depths in drill hole R12 is light brown argillic sandstone with scarce to common light gray and much lesser yellowish gray pumice to 9 mm. Common to abundant black mafics include biotite and hornblende. Lithics to 9 mm are common, all are devitrified lava with conspicuous hornblende and feldspar to 2.5 mm.
R12-730.6	T	Thin section is of a clay-cemented volcaniclastic sandstone. Detrital fragments include both intermediate volcanics and less abundant basalts. Detrital mineral fragments include 0.2 mm grains plagioclase, olivine, clinopyroxene, amphibole, and muscovite as well as 0.1 mm grains of quartz.
R12-751.1	B	Core from 750.7 to 751.1 ft depths in drill hole R12 is grayish orange pink, argillic pumiceous sandstone with common light gray to white and some grayish yellow pumice to 9 mm. Common to abundant mafics are mostly biotite and lesser hornblende. Common lithics to 5 mm are devitrified lava.
R12-751.5	T	Thin section contains clay-altered pumice with sand grains. Mineral fragments in the sand include quartz, feldspar, biotite, muscovite, chlorite, and amphibole. There are sparse developments of carbonate along with the clay.
R12-779.5	B	Core from 779.2 to 779.5 ft depths in drill hole R12 is very pale yellowish brown, argillic pumiceous sandstone with common very light gray pumice to 4 mm, occasionally to 11 mm. Abundant mafics include biotite and hornblende. Common lithics to 3 mm are mostly devitrified lava, but also include a single, 6 mm grayish orange sandstone.
R12-779.5	T	Thin section is of clay-cemented sand. Detrital fragments include altered volcanic clasts and grains of plagioclase, quartz, biotite, amphibole, and chlorite. There are sparse areas of carbonate development in the clay matrix.
R12-810D	B	Cuttings from 809.6 to 810 ft depths in drill hole R12 are medium dark gray, coarse-grained, very slightly vesicular basalt with common iddingsite after olivine to 2 mm. Vesicles, to 1 mm, are very irregular.
R12-810D	T	Olivine basalt with gabbroic texture. Olivine grains to 2 mm, feldspar laths to 1.5 mm in length. Olivine grains are extensively (~75%) altered to iddingsite. Small clinopyroxene grains in groundmass ~0.2 mm. Sparse voids filled by anhedral, tightly intergrown carbonate crystals up to 0.2 mm in size.

* B = description under binocular microscope and T = thin section narratives.

Appendix C

Moisture and Matric-Potential Results

Sample ID*	Matrix Type	Upper Depth (ft)	Lower Depth (ft)	Gravimetric Moisture (%)	Activity (H_20)	Temp. (°C)	Matric Potential (cm)
R12-122A	Cuttings	5	5	2.48	0.981	23.20	-2.74E+04
R12-123A	Cuttings	10	10	2.12	0.985	23.37	-2.18E+04
R12-124A	Cuttings	15	15	4.99	0.987	23.43	-1.82E+04
R12-125A	Cuttings	20	20	6.04	0.984	23.51	-2.32E+04
R12-126	Cuttings	24.9	25	1.90	0.942	23.73	-8.42E+04
R12-127	Cuttings	29.9	30	2.59	0.983	23.37	-2.46E+04
R12-128	Cuttings	33.8	34	3.80	0.985	23.55	-2.18E+04
R12-129	Cuttings	39.5	40	2.98	0.980	23.82	-2.82E+04
R12-130	Cuttings	43.9	44	5.49	0.995	23.69	-7.00E+03
R12-131	Cuttings	48.9	49	6.85	0.996	23.62	-5.59E+03
R12-132	Cuttings	54.8	55	6.29	0.996	23.65	-6.29E+03
R12-133	Cuttings	59.8	60	6.28	0.997	23.70	-4.19E+03
R12-134	Cuttings	64.8	65	5.36	0.995	23.70	-7.00E+03
R12-135	Cuttings	69.8	70	2.65	0.992	23.72	-1.12E+04
R12-136	Cuttings	74.9	75	8.33	0.997	23.77	-4.19E+03
R12-137	Cuttings	79.8	80	9.21	0.998	23.62	-3.49E+03
R12-138	Cuttings	84.8	85	11.48	0.999	23.54	-2.09E+03
R12-139	Cuttings	89.9	90	11.50	1.000	23.61	-3.10E-10
R12-140	Cuttings	94.5	95	11.70	0.999	23.60	-2.09E+03
R12-141	Cuttings	99	100	12.14	0.997	23.62	-4.19E+03
R12-142	Cuttings	104.9	105	19.76	0.999	23.63	-2.09E+03
R12-143	Cuttings	109	110	16.61	1.000	23.63	-6.98E+02
R12-144	Cuttings	114.8	115	20.11	1.001	23.51	6.97E+02
R12-201	Cuttings	119.3	120	12.09	0.999	23.61	-2.09E+03
R12-202	Cuttings	121	122	16.55	0.998	23.72	-2.79E+03
R12-203	Cuttings	129	130	27.20	1.000	23.87	-6.98E+02
R12-204	Cuttings	130.5	131	14.24	0.998	23.97	-3.50E+03
R12-205	Cuttings	131.3	131.5	16.22	0.998	23.93	-3.50E+03
R12-206	Cuttings	133.5	134	8.61	0.995	23.97	-7.00E+03
R12-207	Cuttings	135.8	136	5.71	0.994	24.01	-8.41E+03
R12-208	Cuttings	136.8	137	1.40	0.916	24.34	-1.23E+05
R12-209	Cuttings	138.3	138.5	0.61	0.908	24.42	-1.35E+05
R12-210	Cuttings	139.9	140	2.65	0.992	23.81	-1.19E+04
R12-211	Cuttings	146	147	4.30	0.999	24.64	-2.10E+03
R12-212	Cuttings	150	152	4.34	1.000	24.66	-7.00E+02
R12-213	Cuttings	152	157	2.77	0.995	24.81	-7.73E+03
R12-214	Cuttings	170	172	0.43	0.953	24.83	-6.82E+04
R12-215	Cuttings	180	182	0.52	0.962	24.75	-5.50E+04
R12-1	Cuttings	200	202	1.74	1.000	23.73	-6.98E+02

Sample ID*	Matrix Type	Upper Depth (ft)	Lower Depth (ft)	Gravimetric Moisture (%)	Activity (H_2O)	Temp. (°C)	Matric Potential (cm)
R12-2	Cuttings	218	222	1.32	0.995	23.97	-7.00E+03
R12-3	Cuttings	227.3	228	0.52	0.936	24.30	-9.25E+04
R12-4	Cuttings	236.6	237.5	0.78	0.979	24.24	-2.97E+04
R12-5	Cuttings	248	250	0.85	0.958	24.41	-6.08E+04
R12-6	Cuttings	256	258	10.56	0.991	24.40	-1.34E+04
R12-8	Cuttings	261.5	262	20.04	0.997	24.41	-4.20E+03
R12-7	Cuttings	265	266	3.83	0.993	24.43	-1.05E+04
R12-9	Cuttings	269	270	1.31	0.984	24.46	-2.26E+04
R12-10	Cuttings	277.5	280	0.43	0.828	24.85	-2.65E+05
R12-11	Cuttings	287.5	290	3.11	0.995	24.56	-7.02E+03
R12-12	Cuttings	297	298.5	3.31	0.975	24.41	-3.61E+04
R12-13	Cuttings	299.2	300	3.24	0.982	24.36	-2.61E+04
R12-14	Cuttings	307.8	310	1.05	0.937	24.50	-9.11E+04
R12-15	Cuttings	317.8	320	0.81	0.901	24.36	-1.46E+05
R12-16	Cuttings	327	330	0.76	0.846	24.71	-2.34E+05
R12-17	Cuttings	338	340	2.56	0.994	24.59	-8.43E+03
R12-18	Cuttings	342.95	343	16.26	0.997	24.50	-4.21E+03
R12-19	Cuttings	345.6	346	15.76	0.999	24.57	-1.40E+03
R12-20	Cuttings	348.3	349	14.66	0.987	24.69	-1.83E+04
R12-21	Cuttings	351.9	352	5.46	0.963	25.99	-5.38E+04
R12-22	Cuttings	358	358.5	1.21	0.871	26.36	-1.95E+05
R12-23	Cuttings	369.2	370	1.04	0.843	26.59	-2.42E+05
R12-24	Cuttings	374.5	375.5	1.58	0.942	26.61	-8.42E+04
R12-37	Cuttings	379.2	380	1.21	0.853	26.85	-2.24E+05
R12-38	Cuttings	386.8	388	1.39	0.808	26.99	-3.02E+05
R12-39	Cuttings	395.3	397	0.70	0.687	27.12	-5.30E+05
R12-40	Cuttings	400	401	1.69	0.987	26.52	-1.92E+04
R12-41	Cuttings	406	408	8.03	0.990	26.73	-1.49E+04
R12-216	Core	420.5	420.8	39.04	1.002	26.75	2.11E+03
R12-217	Core	421.2	421.33	59.42	1.004	26.63	4.92E+03
R12-42	Cuttings	438	442	4.15			
R12-44	Cuttings	442	444	15.54	1.002	26.70	2.11E+03
R12-43	Cuttings	444	449	6.39	1.002	26.75	2.11E+03
R12-45	Cuttings	458.6	459	1.19	0.428	26.95	-1.20E+06
R12-33	Core	520.4	520.5	23.46	0.995	26.20	-7.06E+03
R12-34	Core	523.7	523.8	20.70	0.993	26.36	-9.89E+03
R12-35	Cuttings	553.5	555	5.01	0.994	26.53	-8.48E+03
R12-36	Cuttings	559	560	3.23	0.992	26.66	-1.20E+04
R12-49	Cuttings	564	565	4.72	0.992	26.79	-1.13E+04

Sample ID*	Matrix Type	Upper Depth (ft)	Lower Depth (ft)	Gravimetric Moisture (%)	Activity (H_2O)	Temp. (°C)	Matric Potential (cm)
R12-50	Cuttings	569	570	3.90	0.988	26.89	-1.70E+04
R12-51	Cuttings	574	575	5.15	0.990	26.98	-1.49E+04
R12-52	Cuttings	578.85	580	0.61	0.951	27.26	-7.17E+04
R12-53	Cuttings	584.3	585	3.85	0.995	27.14	-7.79E+03
R12-54	Cuttings	589.3	590	5.92	0.994	27.13	-8.50E+03
R12-55	Cuttings	594.3	595	4.75	0.991	26.98	-1.35E+04
R12-56	Cuttings	599.04	600	2.75	0.987	27.02	-1.92E+04
R12-57	Cuttings	604.13	605	3.44	0.982	27.09	-2.64E+04
R12-58	Cuttings	609.45	610	5.35	0.991	27.25	-1.28E+04
R12-59	Cuttings	614	615	3.67	0.990	27.33	-1.49E+04
R12-60	Cuttings	618.7	620	3.91	0.990	27.39	-1.49E+04
R12-61	Cuttings	624.2	625	3.83	0.993	26.72	-1.06E+04
R12-62	Cuttings	628.75	630	6.74	0.991	27.02	-1.35E+04
R12-63	Cuttings	633.75	635	5.95	0.994	27.07	-8.50E+03
R12-64	Cuttings	639	640	2.72	0.980	27.11	-2.85E+04
R12-65	Cuttings	643.9	645	7.95	0.994	27.18	-9.21E+03
R12-66	Cuttings	648.9	650	3.97	0.990	27.26	-1.49E+04
R12-67	Cuttings	653.75	655	3.98	0.993	27.26	-1.06E+04
R12-68	Cuttings	658.9	660	5.56	0.994	27.23	-8.50E+03
R12-69	Cuttings	663.67	665	5.28	0.987	27.11	-1.85E+04
R12-70	Cuttings	672.2	673	9.09	0.876	27.42	-1.88E+05
R12-71	Cuttings	709.2	710	9.26	0.949	26.12	-7.37E+04
R12-72	Cuttings	713.9	715	12.70	0.838	26.79	-2.49E+05
R12-224	Core	719.78	720	42.22	0.960	26.63	-5.75E+04
R12-223	Core	725.45	725.65	36.52	0.970	26.35	-4.36E+04
R12-222	Core	730.3	730.6	20.61	0.993	26.81	-1.06E+04
R12-221	Core	733	733.2	20.60	0.995	26.76	-7.78E+03
R12-122B	Core	742.1	742.2	30.22	0.991	26.81	-1.28E+04
R12-123B	Core	745.8	746	30.70	0.981	26.70	-2.78E+04
R12-220	Core	750.7	751.1	31.35	0.996	26.75	-5.65E+03
R12-5201A	Core	755.9	756	38.04	0.983	26.65	-2.42E+04
R12-273	Core	760.85	761	28.16	0.994	26.94	-9.20E+03
R12-274	Core	765.7	766	30.41	0.992	26.93	-1.20E+04
R12-275	Core	770.8	771	29.70	0.992	26.91	-1.13E+04
R12-276	Core	775.25	775.45	20.86	0.989	26.83	-1.63E+04
R12-277	Core	779.2	779.5	23.26	0.928	26.62	-1.05E+05
R12-124B	Cuttings	804.66	805	2.85	0.982	26.55	-2.56E+04
R12-125B	Cuttings	809.64	810	1.34	0.480	27.36	-1.04E+06

* See Appendix A.

Appendix D

Results of Unsaturated Hydraulic-Property Testing

This appendix consists of the actual laboratory sheets provided by Daniel B. Stephens & Associates, Inc., for analysis of three samples.

8806A	old alluvium (lake beds), from a depth of 520.0 to 520.4 ft
8807	Puye Formation (pumiceous sandstone), from a depth of 721.0 to 721.5 ft
8805	Puye Formation (sandstone/conglomerate), from a depth of 753.0 to 753.4 ft

In this appendix, results

- are grouped by sample number rather than test type, and
- are presented in order of increasing depth rather than sample number.

Daniel B. Stephens & Associates, Inc.

Data for Initial Moisture Content, Bulk Density, Porosity, and Percent Saturation

Job Name:	LANL
Job Number:	9958.01
Sample Number:	8806A
Ring Number:	8806A
Depth:	NA
Test Date:	8-Sep-99

Field weight of sample* (g):	524.53
Tare weight, ring (g):	133.26
Tare weight, cap/plate/epoxy (g):	0.00
Dry weight of sample (g):	316.98
Sample volume (cm^3):	192.70
Assumed particle density:	2.65

Initial Volumetric Moisture Content (% vol):	38.6
Initial Gravimetric Moisture Content (% g/g):	23.4
Dry bulk density (g/cm^3):	1.64
Wet bulk density (g/cm^3):	2.03
Calculated Porosity (% vol):	37.9
Percent Saturation:	101.6

Comments:

* Weight including tares

Laboratory analysis by:	C. Pigman
Data entered by:	R. Smith
Checked by:	R. Smith

Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity
Falling Head Method

Job name:	LANL	*Type of water used:*	TAP
Job number:	9958.01	*Backpressure* (psi):	0.0
Sample number:	8806A	*Offset* (cm):	2.7
Ring number:	8806A	*Sample length* (cm):	3.38
Depth:	NA	*Sample x-sectional area* (cm^2):	57.01
		Reservoir x-sectional area (cm^2):	0.70

Date	Time	Temp (°C)	Reservoir head (cm)	Corrected head (cm)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:							
09-Sep-99	19:44:26	19.0	77.7	75.0	50626	2.9E-07	2.9E-07
10-Sep-99	09:48:12	20.0	55.6	52.9			
Test # 2:							
10-Sep-99	09:48:12	20.0	55.6	52.9	29579	2.7E-07	2.7E-07
10-Sep-99	18:01:11	19.0	46.3	43.6			
Test # 3:							
13-Sep-99	16:14:31	19.5	54.4	51.7	66961	2.8E-07	2.9E-07
14-Sep-99	10:50:32	19.0	35.5	32.8			

***Average Ksat* (cm/sec): 2.8E-07**

Comments:

Laboratory analysis by: E. Koenig
Data entered by: M. Devine
Checked by: R. Smith

Daniel B. Stephens & Associates, Inc.

Moisture Retention Data

Hanging Column/Pressure Plate/Thermocouple

(Main Drainage Curve)

Job Name:	LANL	*Dry wt. of sample* (g)*:*	316.98
Job Number:	9958.01	*Tare wt., screen & clamp* (g)*:*	31.72
Sample Number:	8806A	*Tare wt., ring* (g)*:*	133.26
Ring Number:	8806A	*Tare wt., epoxy* (g)*:*	0.00
Depth:	NA	*Sample volume* (cm^3)*:*	192.70

Saturated weight at 0 cm tension* (g)*:*	564.29
Volume of water † *in saturated sample* (cm^3)*:*	82.33
Saturated moisture content (% vol)*:*	42.72
Sample bulk density (g/cm^3)*:*	1.64

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content† (% vol)
Hanging column:	20-Sep-99 / 18:15	564.29	0.00	42.72
	23-Sep-99 / 13:23	562.03	26.70	41.55
	27-Sep-99 / 14:01	558.57	127.80	39.76
Pressure plate:	29-Sep-99 / 19:03	554.88	520.10	37.84

Dry weight of thermocouple sample* (g)*:*	273.28
Tare weight, jar (g)*:*	172.41
Sample bulk density (g/cm^3)*:*	1.64

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content† (% vol)
Thermocouple:	04-Oct-99 / 16:40	287.32	8872.3	22.90
	05-Oct-99 / 12:22	285.45	17744.5	19.85

Comments:

* Weight including tares
† Assumed density of water is 1.0 g/cm^3

Laboratory analysis by:	E. Koenig/R. Smith
Data entered by:	M. Devine
Checked by:	R. Smith

Daniel B. Stephens & Associates, Inc.

Moisture Retention Data

Relative Humidity Box

(Main Drainage Curve)

Job Name: LANL
Job Number: 9958.01
Sample Number: 8806A
Ring Number: 8806A
Depth: NA

Dry weight of relative humidity box sample* (g): 93.17
Tare weight (g): 42.09
Sample bulk density (g/cm^3): 1.64

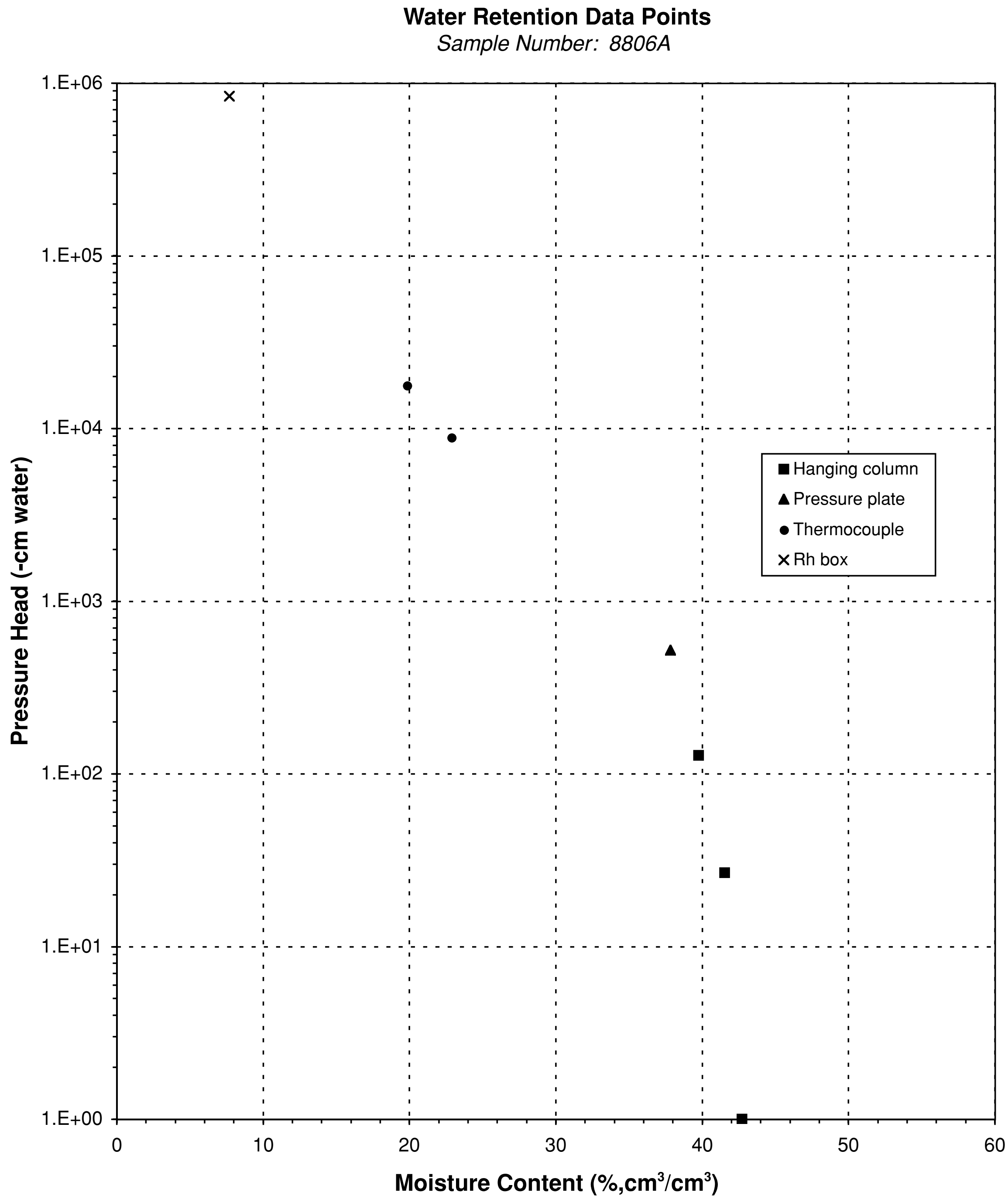
	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content† (% vol)
Relative humidity box:	22-Sep-99 / 08:35	95.56	836961	7.69

Comments:

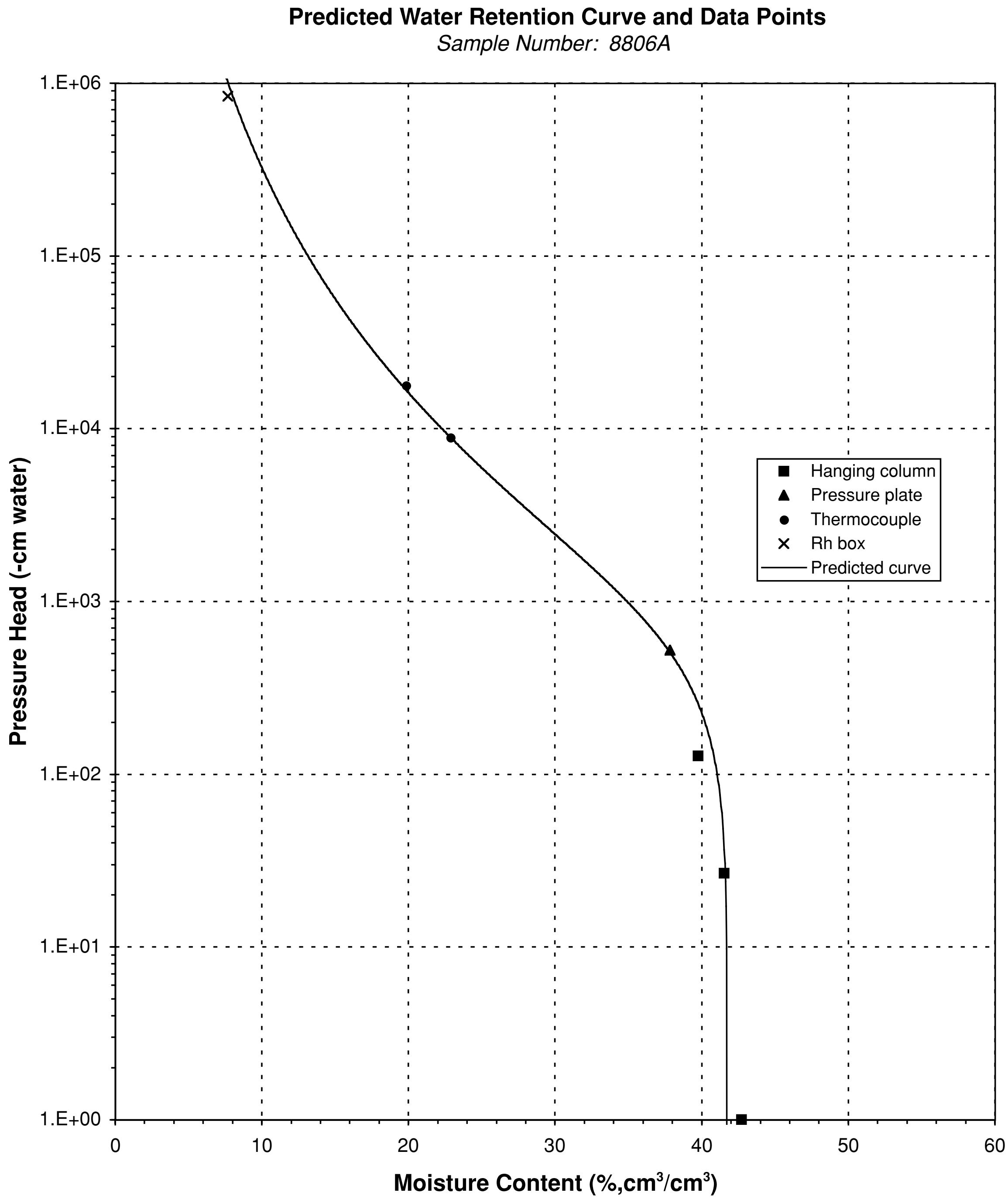
* Weight including tares
† Assumed density of water is 1.0 g/cm^3

Laboratory analysis by: M. Devine
Data entered by: M. Devine
Checked by: R. Smith

Daniel B. Stephens & Associates, Inc.



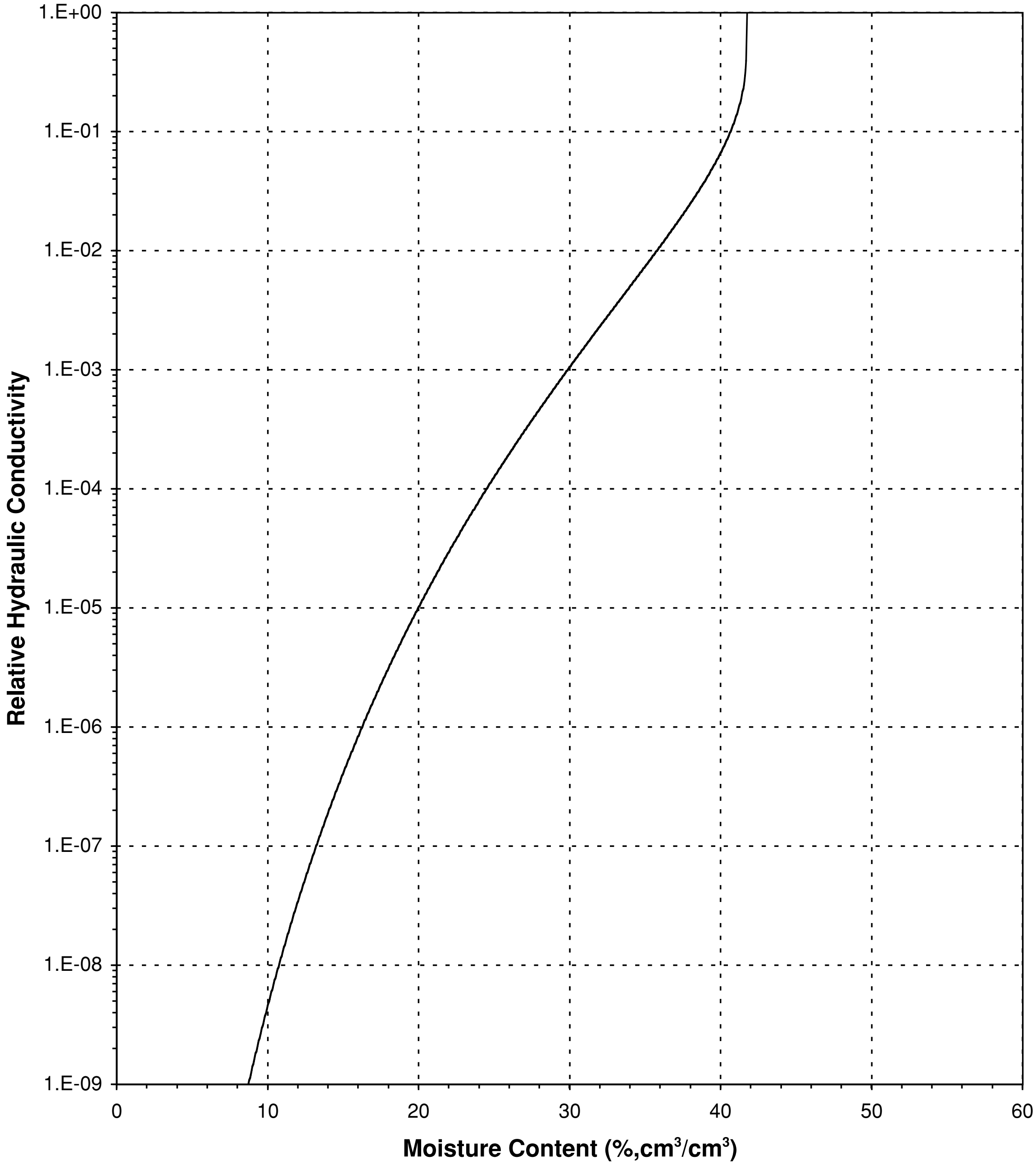
Daniel B. Stephens & Associates, Inc.



Daniel B. Stephens & Associates, Inc.

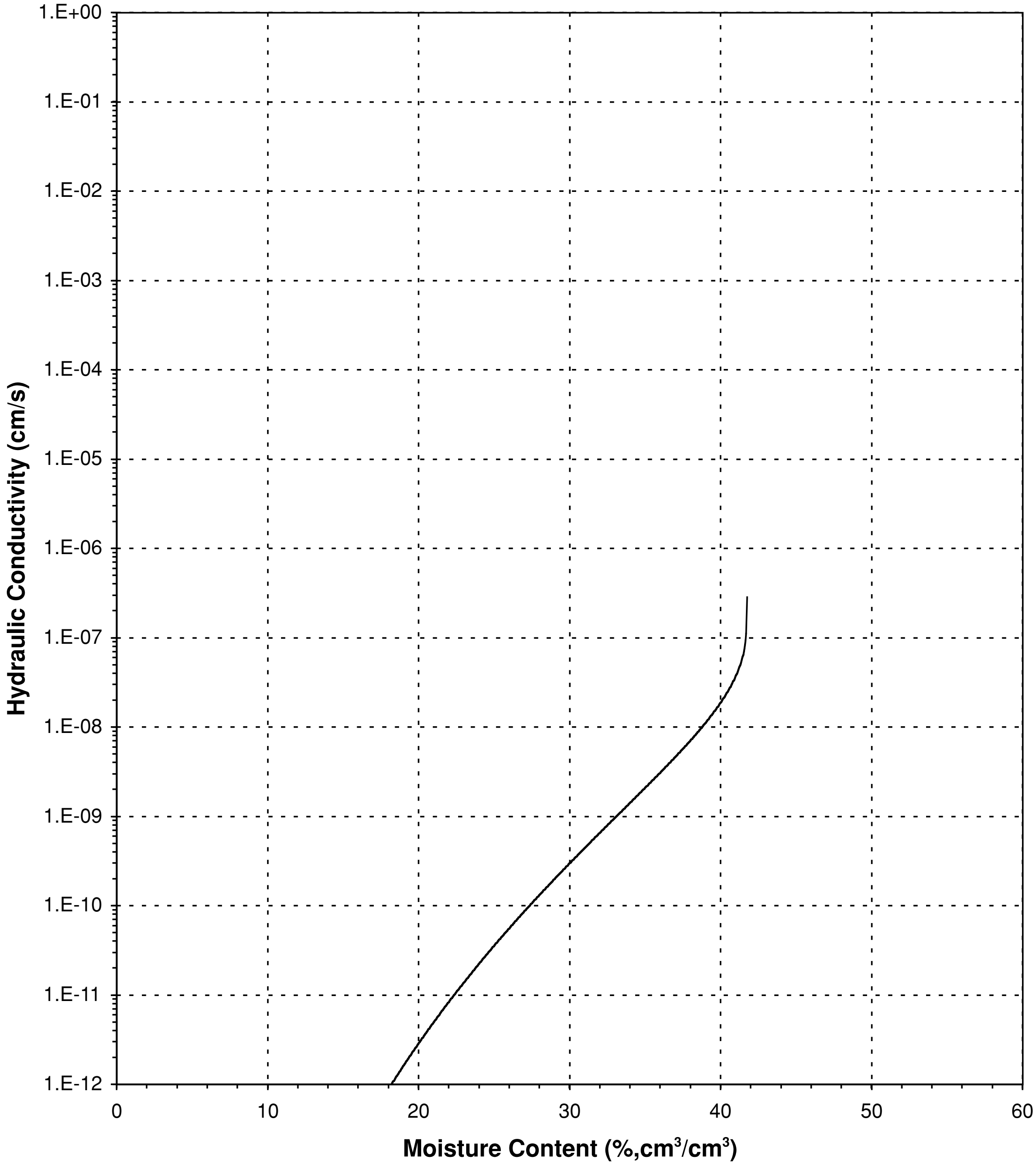
Plot of Relative Hydraulic Conductivity vs Moisture Content

Sample Number: 8806A



Daniel B. Stephens & Associates, Inc.

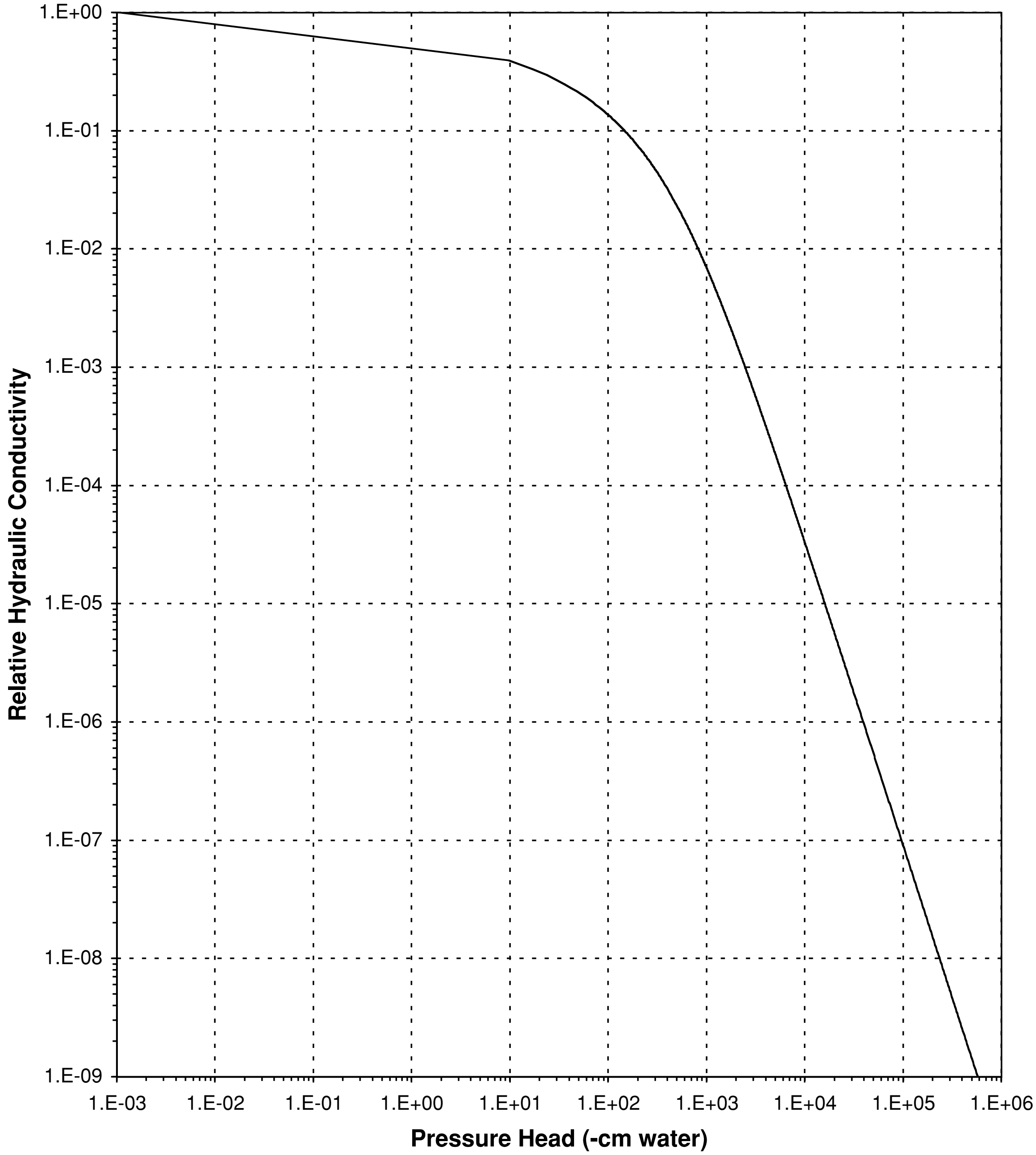
Plot of Hydraulic Conductivity vs Moisture Content
Sample Number: 8806A



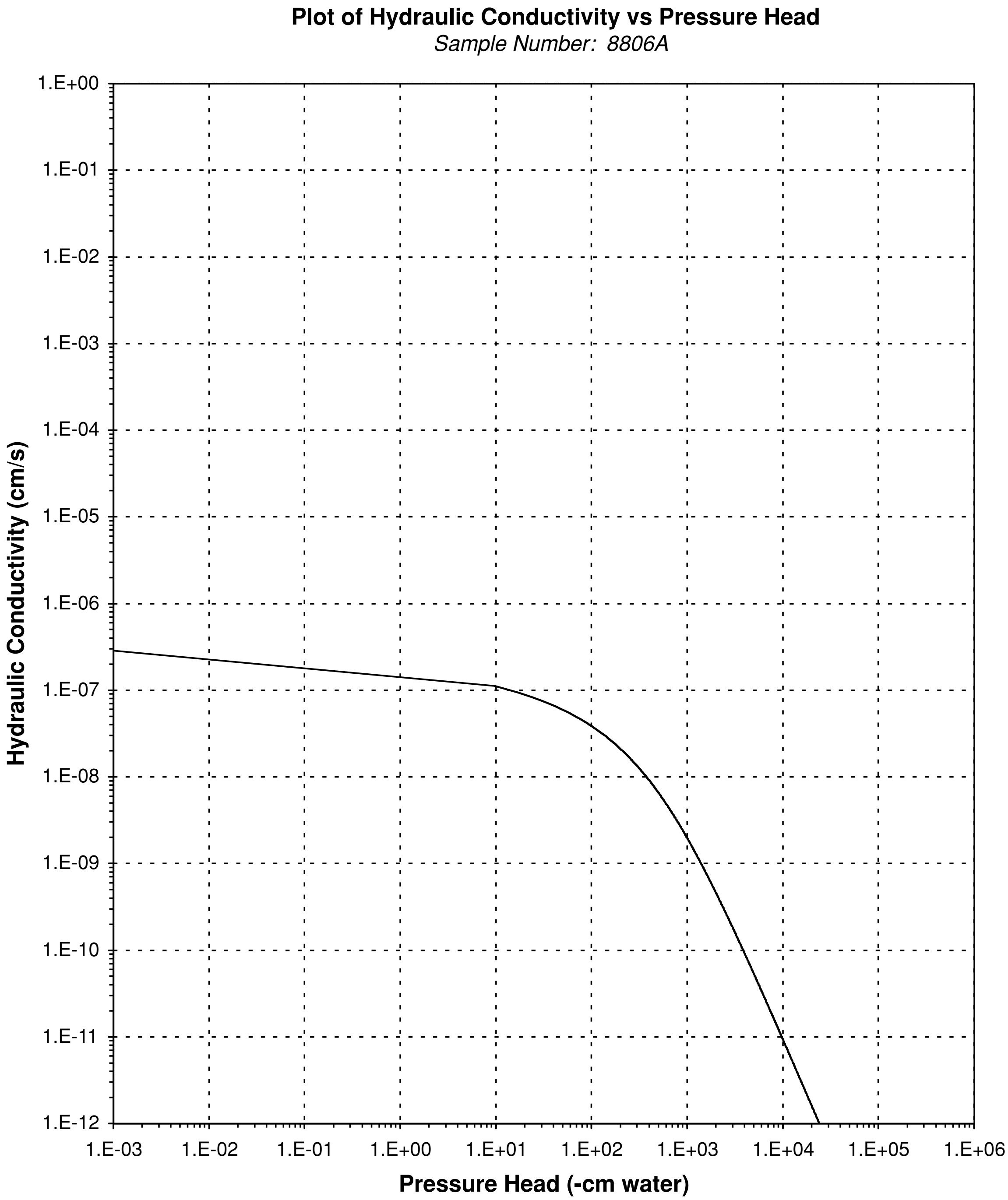
Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Pressure Head

Sample Number: 8806A



Daniel B. Stephens & Associates, Inc.



Daniel B. Stephens & Associates, Inc.

Data for Initial Moisture Content, Bulk Density, Porosity, and Percent Saturation

Job Name:	LANL
Job Number:	9958.01
Sample Number:	8807
Ring Number:	8807
Depth:	NA
Test Date:	8-Sep-99

Field weight of sample* (g):	253.68
Tare weight, ring (g):	120.63
Tare weight, cap/plate/epoxy (g):	0.00
Dry weight of sample (g):	94.00
Sample volume (cm^3):	74.66
Assumed particle density:	2.65

Initial Volumetric Moisture Content (% vol):	52.3
Initial Gravimetric Moisture Content (% g/g):	41.5
Dry bulk density (g/cm^3):	1.26
Wet bulk density (g/cm^3):	1.78
Calculated Porosity (% vol):	52.5
Percent Saturation:	99.6

Comments:

* Weight including tares

Laboratory analysis by:	C. Pigman
Data entered by:	R. Smith
Checked by:	R. Smith

Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity
Falling Head Method

Job name: LANL
Job number: 9958.01
Sample number: 8807
Ring number: 8807
Depth: NA

Type of water used: TAP
Backpressure (psi)*:* 15.0
Offset (cm)*:* 1.2
Sample length (cm)*:* 2.58
Sample x-sectional area (cm^2)*:* 28.94
Reservoir x-sectional area (cm^2)*:* 0.70

Date	Time	Temp (°C)	Reservoir head (cm)	Corrected head (cm)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:							
08-Oct-99	08:19:59	18.0	63.0	1116.5	19871	1.4E-09	1.4E-09
08-Oct-99	13:51:10	19.0	62.5	1116.0			
Test # 2:							
11-Oct-99	12:11:27	18.0	71.3	1124.8	17103	1.6E-09	1.7E-09
11-Oct-99	16:56:30	19.0	70.8	1124.3			
Test # 3:							
11-Oct-99	16:56:30	19.0	70.8	1124.3	55390	1.5E-09	1.5E-09
12-Oct-99	08:19:40	17.5	69.4	1122.8			

Average Ksat* (cm/sec)*: **1.5E-09**

Comments:

Laboratory analysis by: R. Smith
Data entered by: M. Devine
Checked by: R. Smith

Daniel B. Stephens & Associates, Inc.

Moisture Retention Data

Hanging Column/Pressure Plate/Thermocouple

(Main Drainage Curve)

Job Name:	LANL	*Dry wt. of sample* (g):	94.00
Job Number:	9958.01	*Tare wt., screen & clamp* (g):	0.63
Sample Number:	8807	*Tare wt., ring* (g):	120.63
Ring Number:	8807	*Tare wt., epoxy* (g):	0.00
Depth:	NA	*Sample volume* (cm^3):	74.66

Saturated weight at 0 cm tension* (g):	261.74
Volume of water † *in saturated sample* (cm^3):	46.48
Saturated moisture content (% vol):	62.26
Sample bulk density (g/cm^3):	1.26

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content† (% vol)
Hanging column:	11-Nov-99 / 14:10	261.74	0.00	62.26
	15-Nov-99 / 10:20	260.52	51.70	60.62
	17-Nov-99 / 19:30	259.79	130.60	59.64
Pressure plate:	20-Nov-99 / 19:30	259.30	494.60	58.99

Dry weight of thermocouple sample* (g):	245.79
Tare weight, jar (g):	166.69
Sample bulk density (g/cm^3):	1.26

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content† (% vol)
Thermocouple:	29-Sep-99 / 15:13	275.40	9790.1	47.13
	30-Sep-99 / 17:29	273.32	21313.8	43.82

Comments:

* Weight including tares
† Assumed density of water is 1.0 g/cm^3

Laboratory analysis by: E. Koenig/R. Smith
Data entered by: M. Devine
Checked by: R. Smith

Daniel B. Stephens & Associates, Inc.

Moisture Retention Data

Relative Humidity Box

(Main Drainage Curve)

Job Name:	LANL
Job Number:	9958.01
Sample Number:	8807
Ring Number:	8807
Depth:	NA

Dry weight of relative humidity box sample* (g):	77.82
Tare weight (g):	44.85
Sample bulk density (g/cm^3):	1.26

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content† (% vol)
Relative humidity box:	17-Dec-99 / 08:30	81.78	848426	15.11

Comments:

* Weight including tares

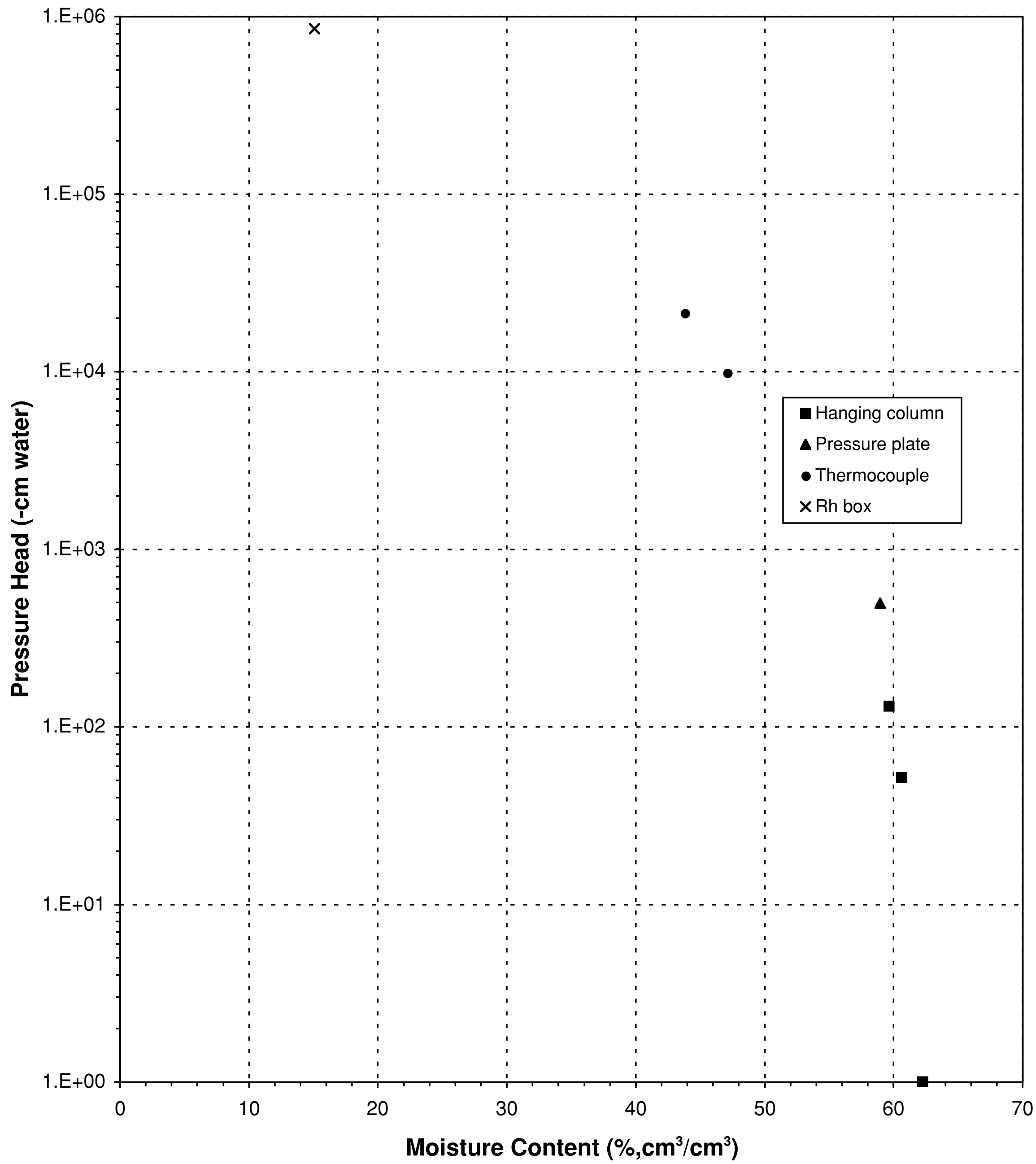
† Assumed density of water is 1.0 g/cm^3

Laboratory analysis by:	B. Baum
Data entered by:	M. Devine
Checked by:	R. Smith

Daniel B. Stephens & Associates, Inc.

Water Retention Data Points

Sample Number: 8807



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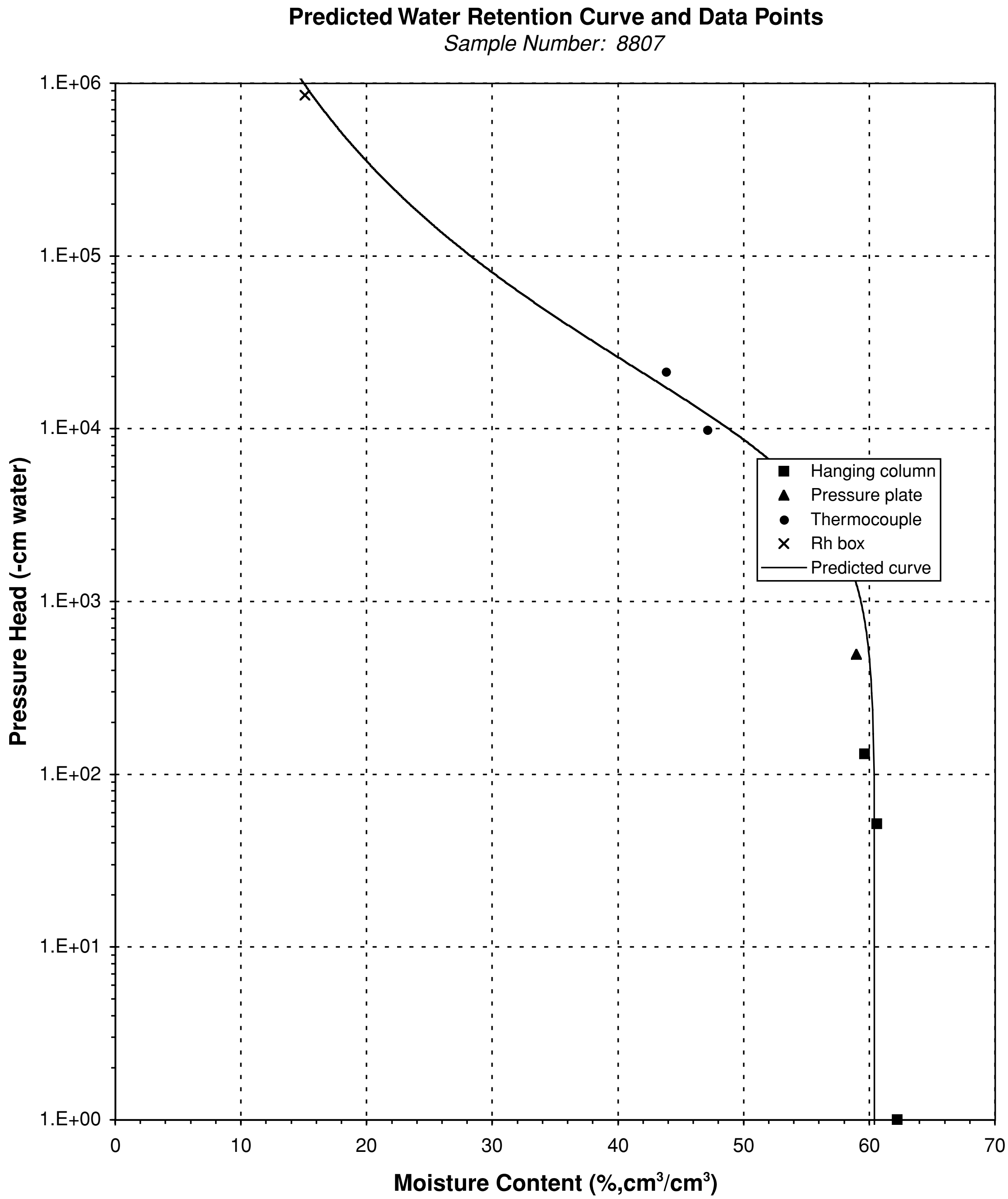

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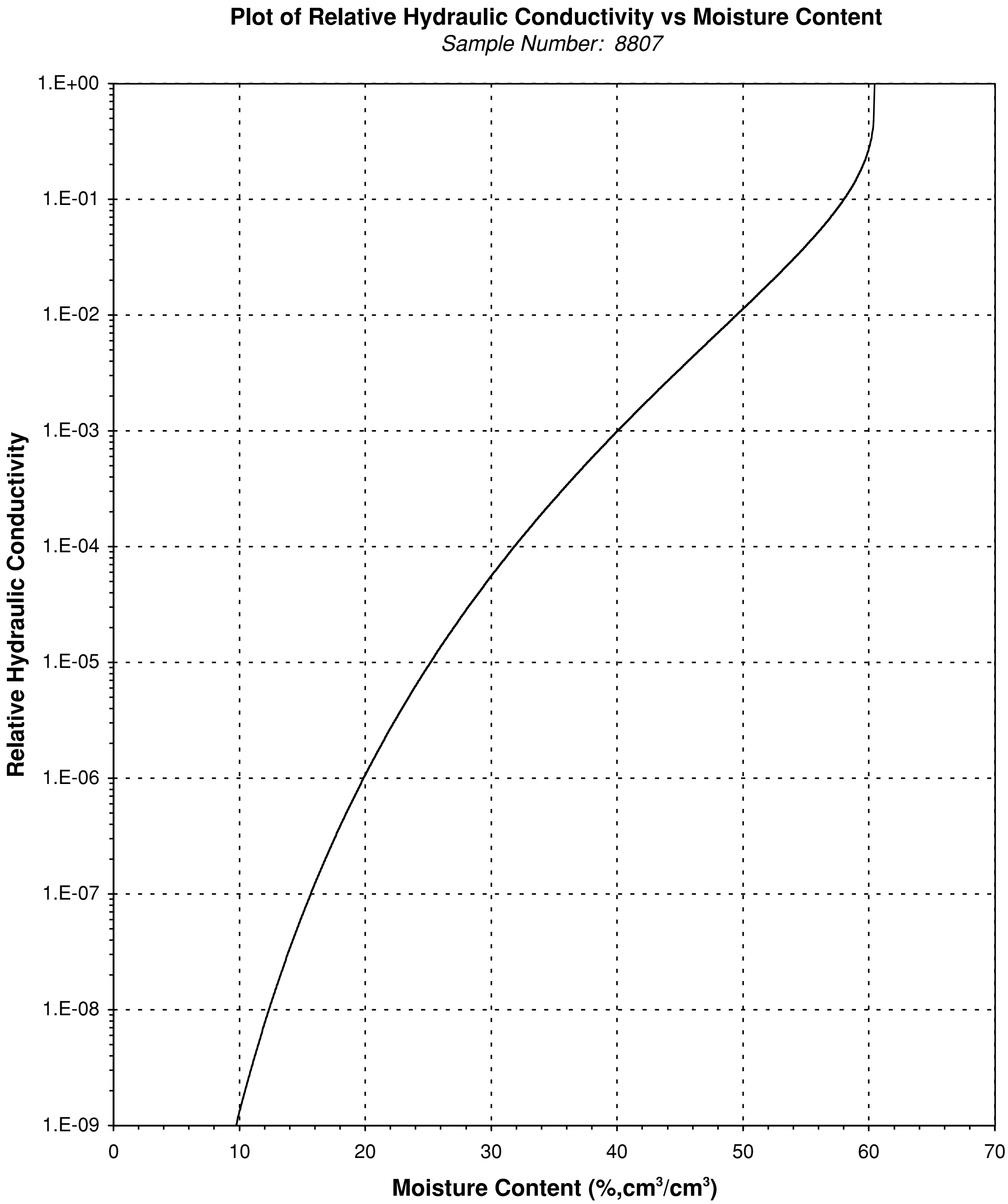
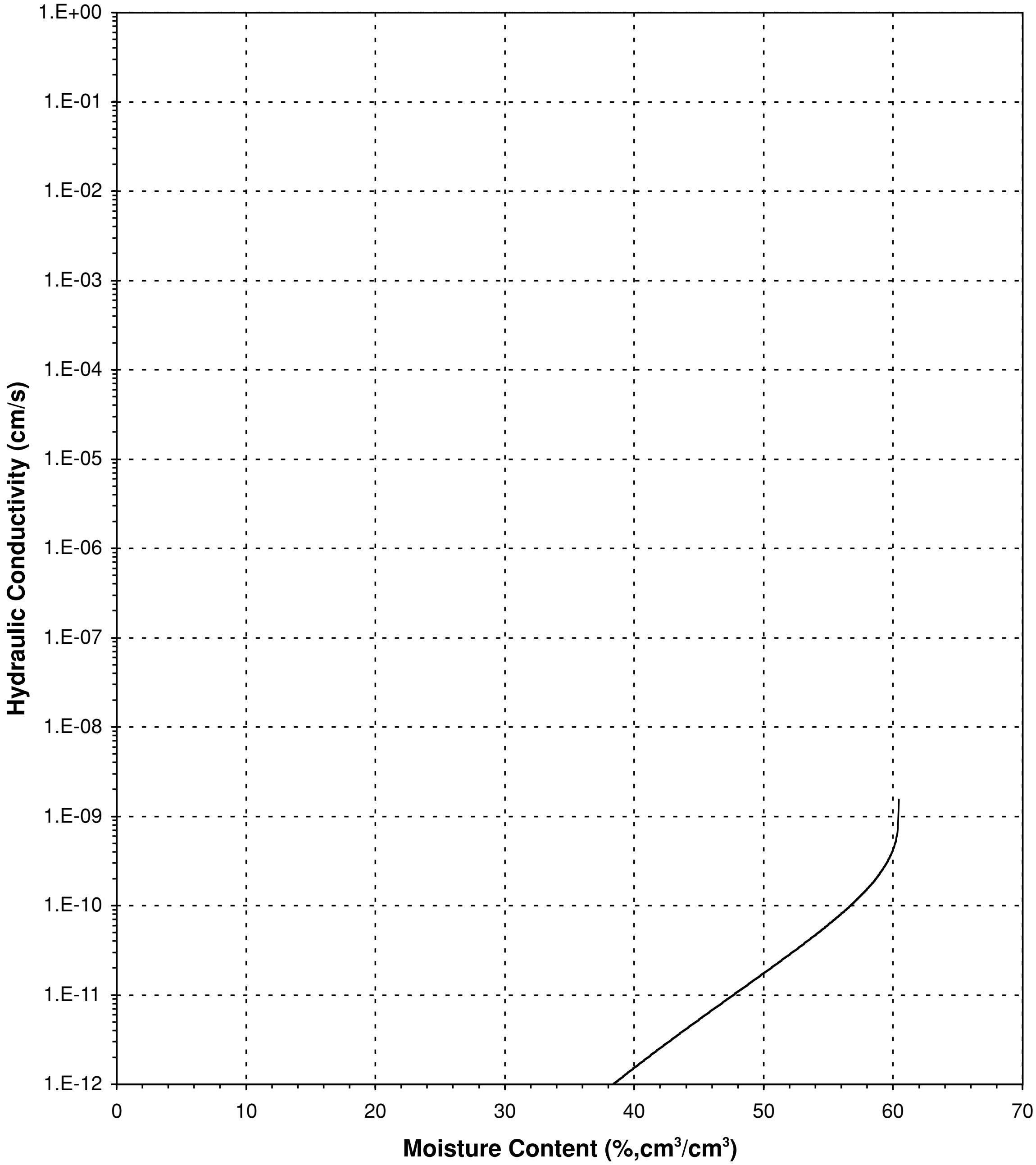


Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Moisture Content

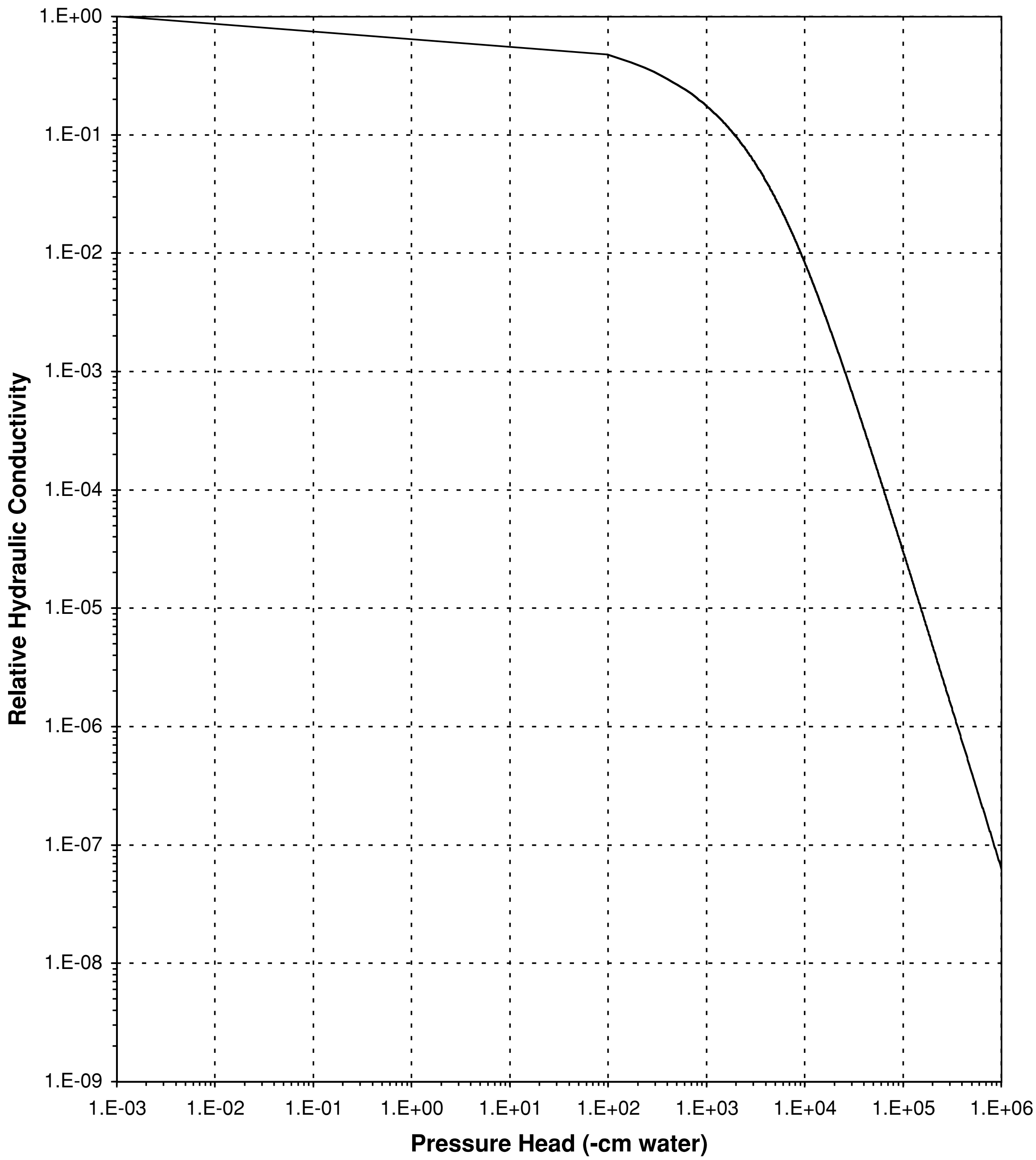
Sample Number: 8807



Daniel B. Stephens & Associates, Inc.

Plot of Relative Hydraulic Conductivity vs Pressure Head

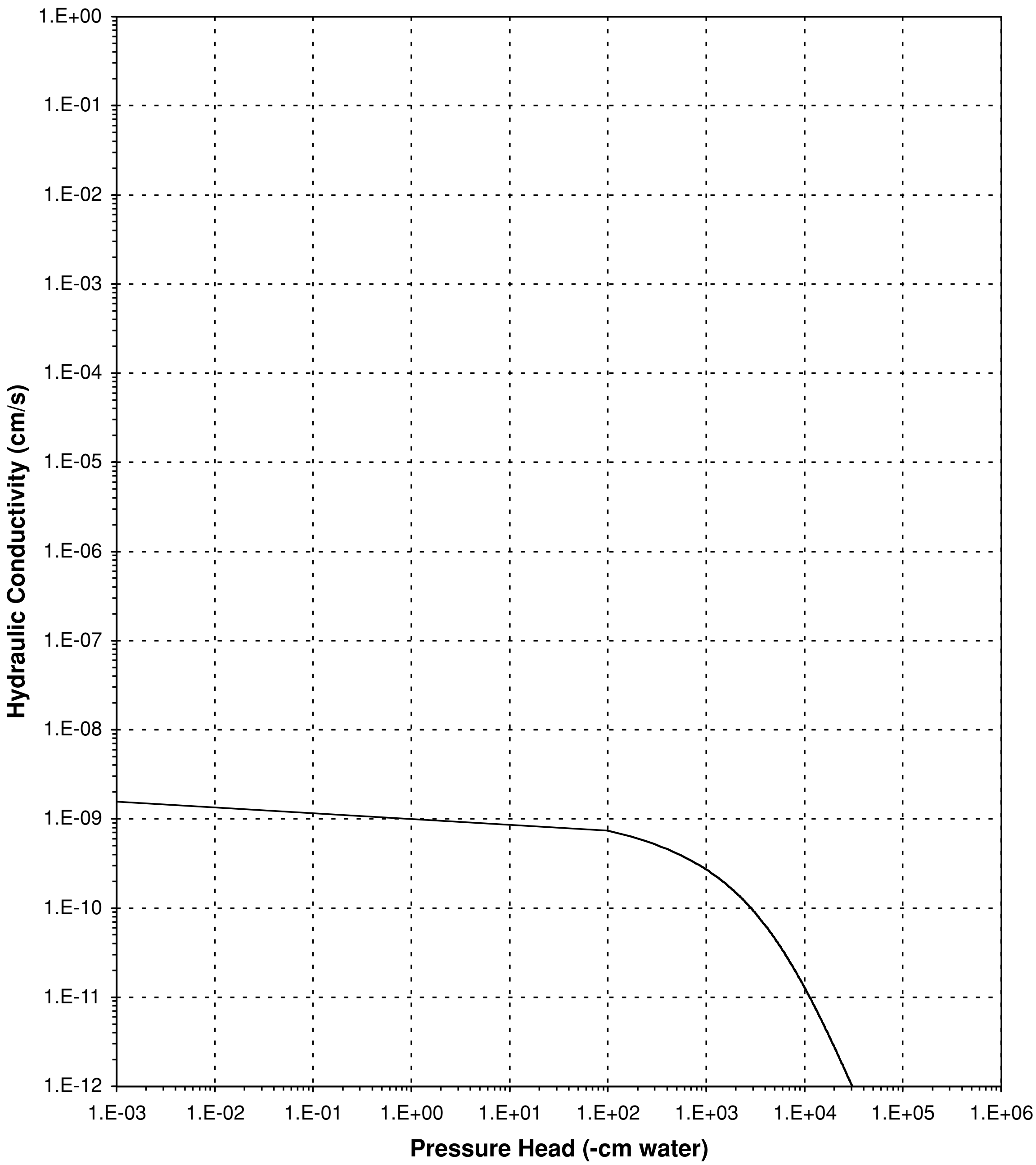
Sample Number: 8807



Daniel B. Stephens & Associates, Inc.

Plot of Hydraulic Conductivity vs Pressure Head

Sample Number: 8807



Daniel B. Stephens & Associates, Inc.

Data for Initial Moisture Content, Bulk Density, Porosity, and Percent Saturation

Job Name:	LANL
Job Number:	9958.01
Sample Number:	8805
Ring Number:	8805
Depth:	NA
Test Date:	14-Sep-99

Field weight of sample* (g):	253.15
Tare weight, ring (g):	127.14
Tare weight, cap/plate/epoxy (g):	0.00
Dry weight of sample (g):	104.36
Sample volume (cm^3):	61.97
Assumed particle density:	2.65

Initial Volumetric Moisture Content (% vol):	34.9
Initial Gravimetric Moisture Content (% g/g):	20.7
Dry bulk density (g/cm^3):	1.68
Wet bulk density (g/cm^3):	2.03
Calculated Porosity (% vol):	36.4
Percent Saturation:	95.9

Comments:

* Weight including tares

Laboratory analysis by:	M. Devine
Data entered by:	R. Smith
Checked by:	R. Smith

Daniel B. Stephens & Associates, Inc.

Saturated Hydraulic Conductivity
Falling Head Method

Job name:	LANL	*Type of water used:*	TAP
Job number:	9958.01	*Backpressure* (psi):	0.0
Sample number:	8805	*Offset* (cm):	1.3
Ring number:	8805	*Sample length* (cm):	2.53
Depth:	NA	*Sample x-sectional area* (cm^2):	24.46
		Reservoir x-sectional area (cm^2):	0.70

Date	Time	Temp (°C)	Reservoir head (cm)	Corrected head (cm)	Elapsed time (sec)	Ksat (cm/sec)	Ksat @ 20°C (cm/sec)
Test # 1:							
18-Sep-99	11:01:50	20.0	21.5	20.2	163380	9.5E-07	9.4E-07
20-Sep-99	08:24:50	20.0	3.7	2.4			
Test # 2:							
20-Sep-99	09:58:50	20.0	35.4	34.1	30622	9.4E-07	9.5E-07
20-Sep-99	18:29:12	19.0	24.2	22.9			
Test # 3:							
21-Sep-99	19:15:37	19.0	33.8	32.5	50373	9.2E-07	9.4E-07
22-Sep-99	09:15:10	18.5	18.5	17.2			

***Average Ksat* (cm/sec): 9.4E-07**

Comments:

Laboratory analysis by: R. Smith
Data entered by: M. Devine
Checked by: R. Smith

Daniel B. Stephens & Associates, Inc.

Moisture Retention Data

Hanging Column/Pressure Plate/Thermocouple

(Main Drainage Curve)

Job Name:	LANL	*Dry wt. of sample* (g):	104.36
Job Number:	9958.01	*Tare wt., screen & clamp* (g):	1.97
Sample Number:	8805	*Tare wt., ring* (g):	127.14
Ring Number:	8805	*Tare wt., epoxy* (g):	0.00
Depth:	NA	*Sample volume* (cm^3):	61.97

Saturated weight at 0 cm tension* (g):	287.04
Volume of water † *in saturated sample* (cm^3):	53.57
Saturated moisture content (% vol):	86.45
Sample bulk density (g/cm^3):	1.68

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content† (% vol)
Hanging column:	24-Sep-99 / 22:20	287.04	0.00	86.45
	27-Sep-99 / 10:00	287.40	6.00	87.03
	01-Oct-99 / 15:30	286.61	31.00	85.76
	04-Oct-99 / 09:30	284.49	123.70	82.34
Pressure plate:	06-Oct-99 / 15:40	280.21	509.90	75.43

Dry weight of thermocouple sample* (g):	264.40
Tare weight, jar (g):	172.50
Sample bulk density (g/cm^3):	1.68

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content† (% vol)
Thermocouple:	24-Sep-99 / 18:41	286.64	15399.0	40.76

Comments:

* Weight including tares
† Assumed density of water is 1.0 g/cm^3

Laboratory analysis by:	E. Koenig/T. Gere
Data entered by:	M. Devine
Checked by:	R. Smith

Daniel B. Stephens & Associates, Inc.

Moisture Retention Data

Relative Humidity Box

(Main Drainage Curve)

Job Name:	LANL
Job Number:	9958.01
Sample Number:	8805
Ring Number:	8805
Depth:	NA

Dry weight of relative humidity box sample* (g):	70.98
Tare weight (g):	33.89
Sample bulk density (g/cm^3):	1.68

	Date/Time	Weight* (g)	Matric Potential (-cm water)	Moisture Content† (% vol)
Relative humidity box:	15-Dec-99 / 09:02	77.17	848426	28.10

Comments:

* Weight including tares

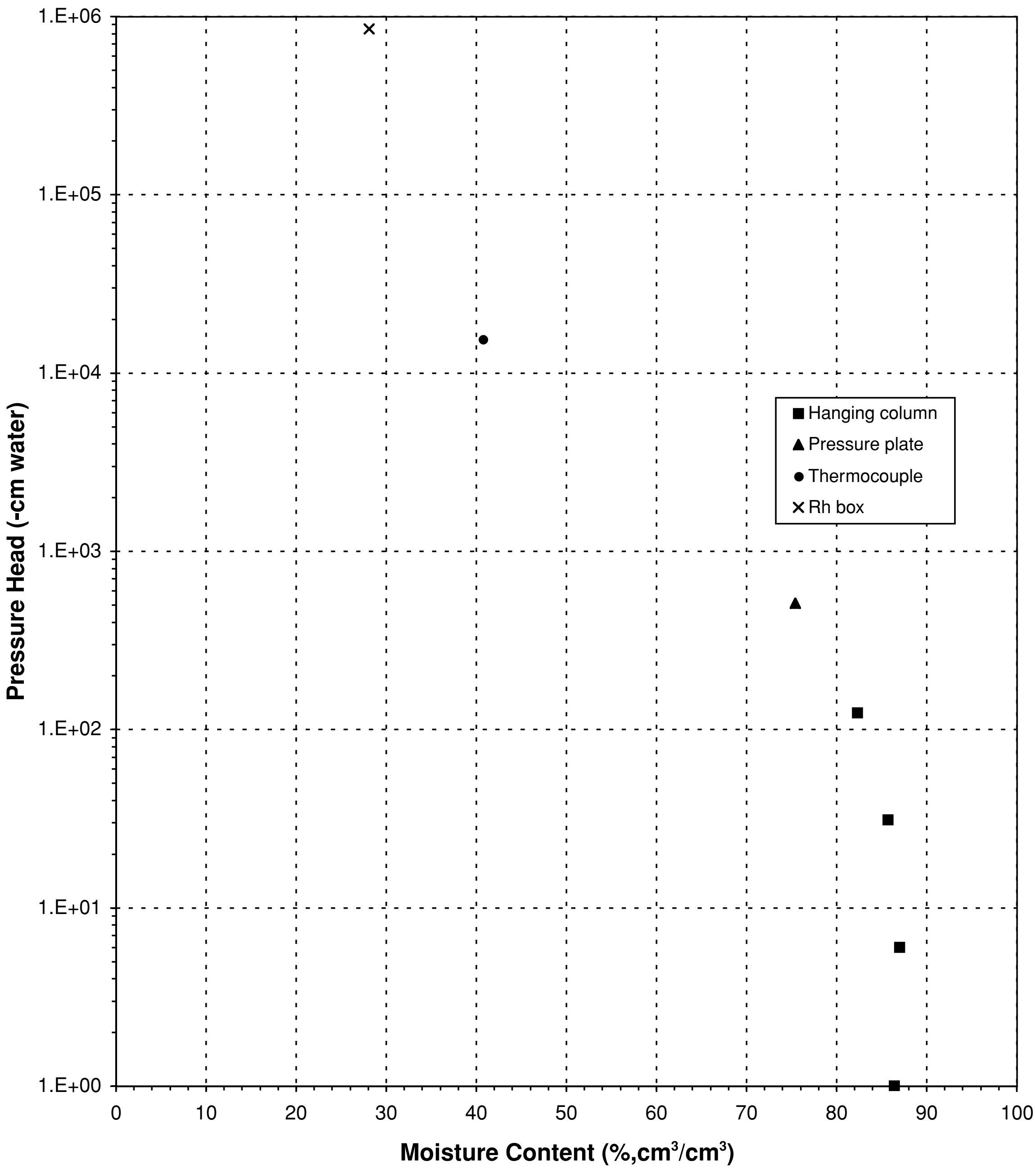
† Assumed density of water is 1.0 g/cm^3

Laboratory analysis by:	B. Baum
Data entered by:	M. Devine
Checked by:	R. Smith

D a n i e l B . S t e p h e n s & A s s o c i a t e s , I n c .

Water Retention Data Points

Sample Number: 8805



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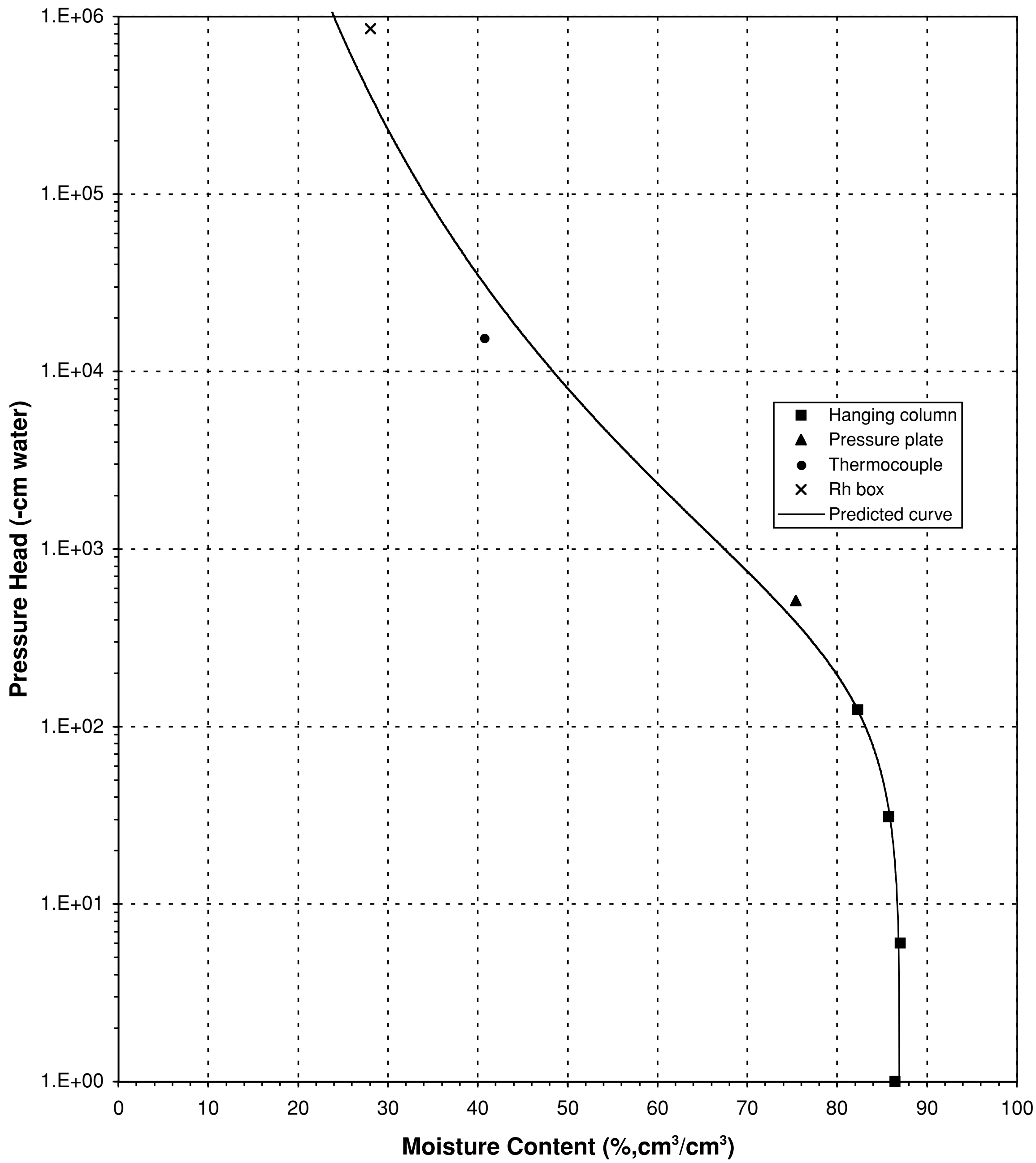
Predicted Water Retention Curve and Data Points

Sample Number: 8805



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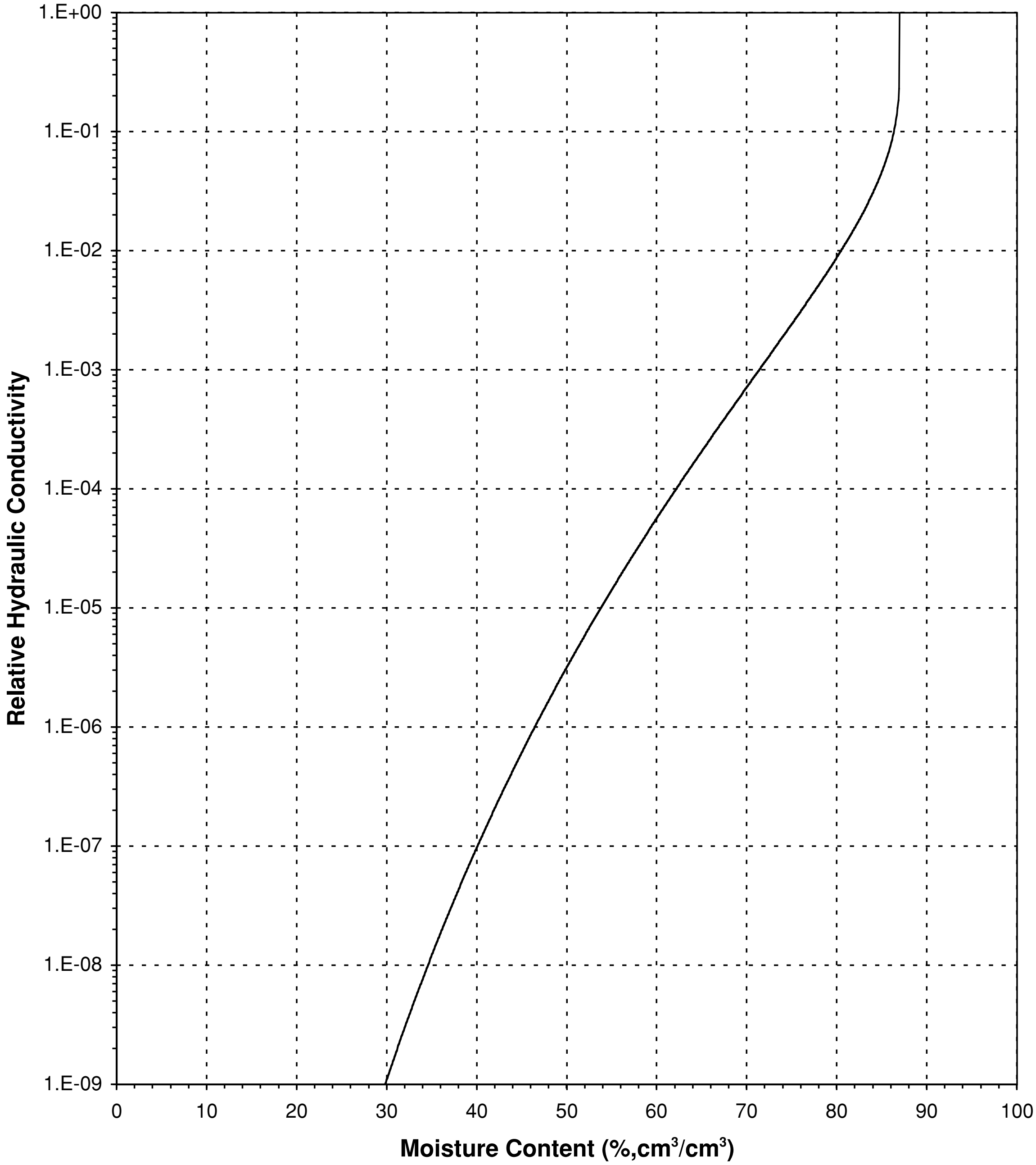
Plot of Relative Hydraulic Conductivity vs Moisture Content

Sample Number: 8805



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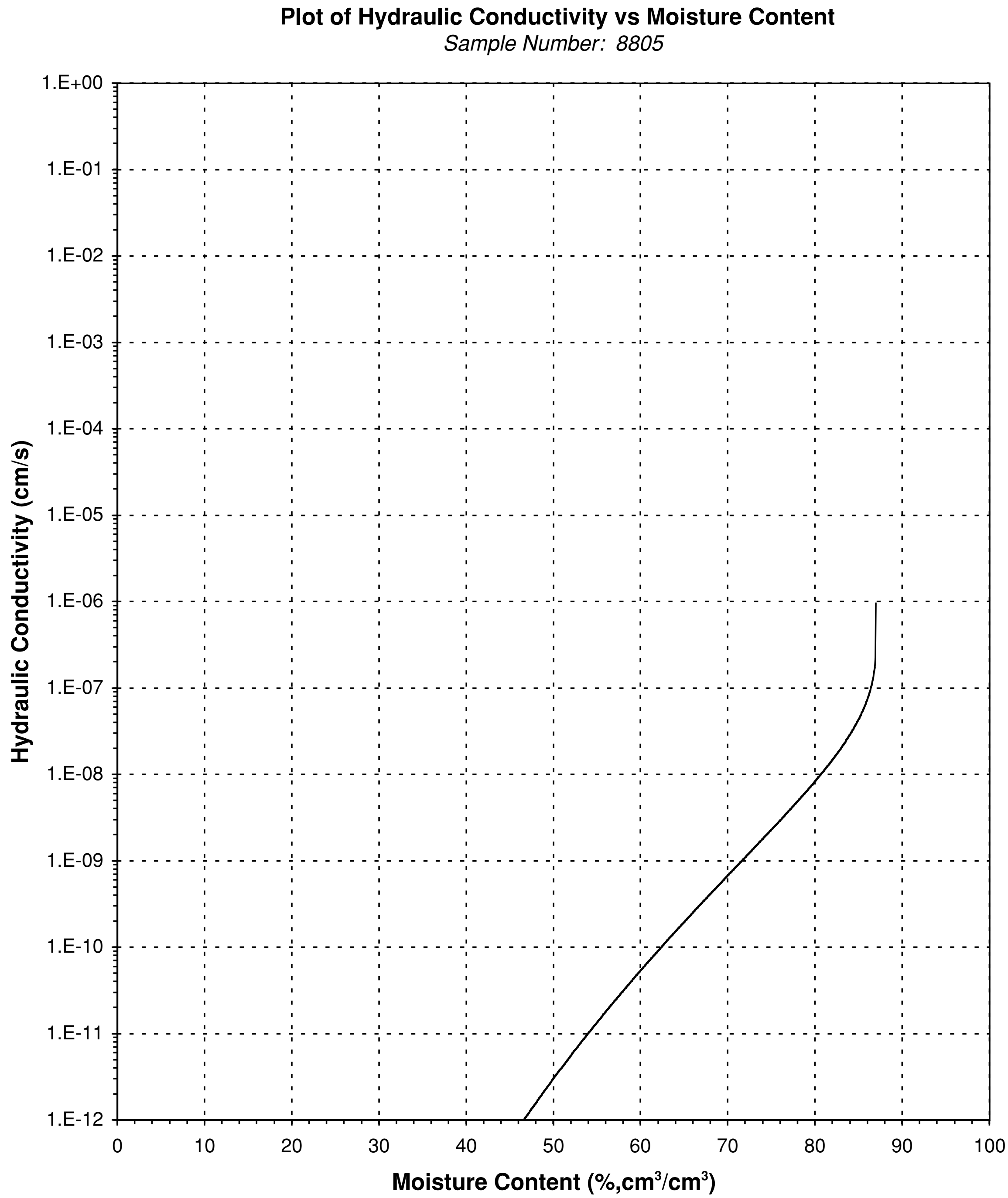

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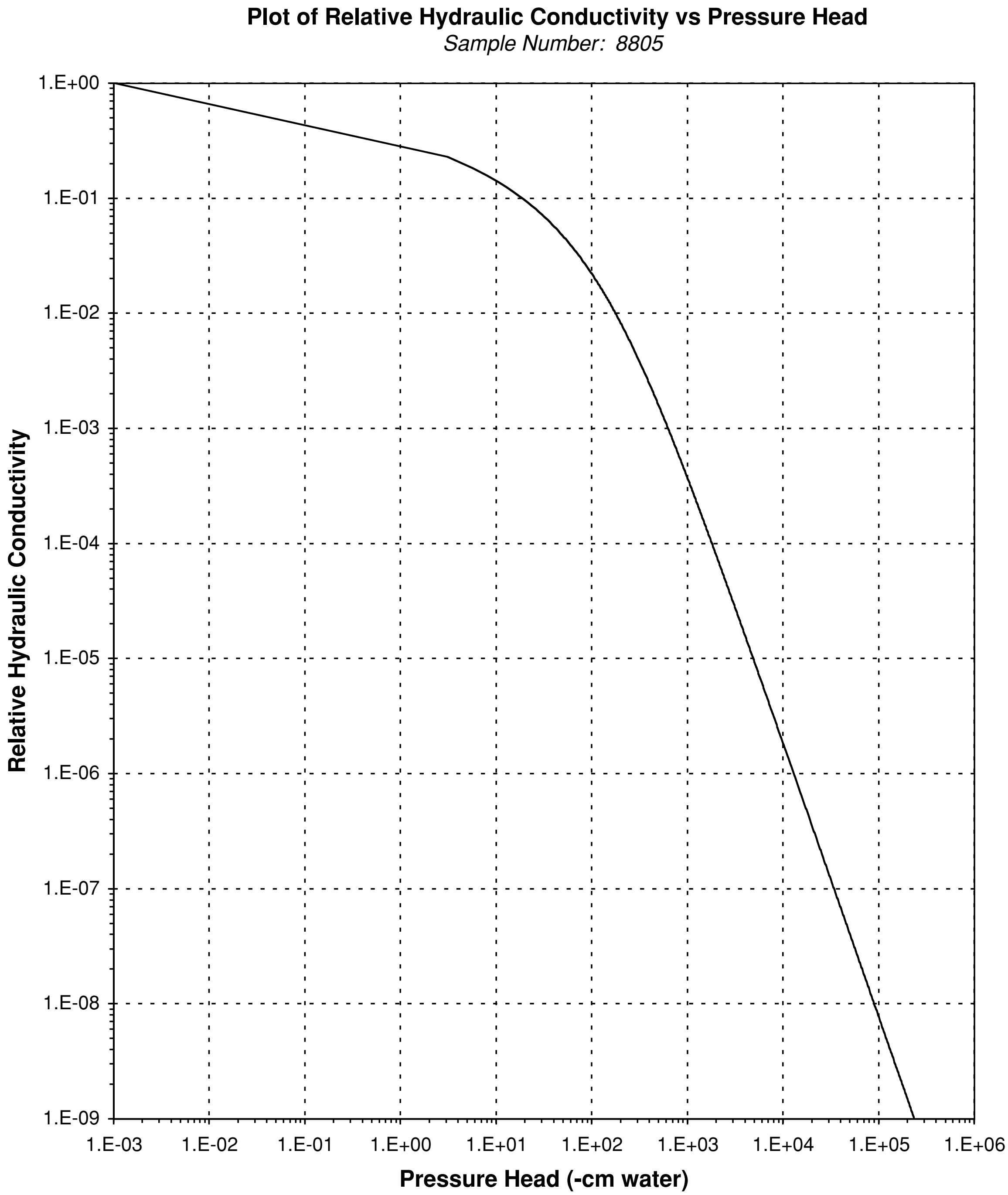

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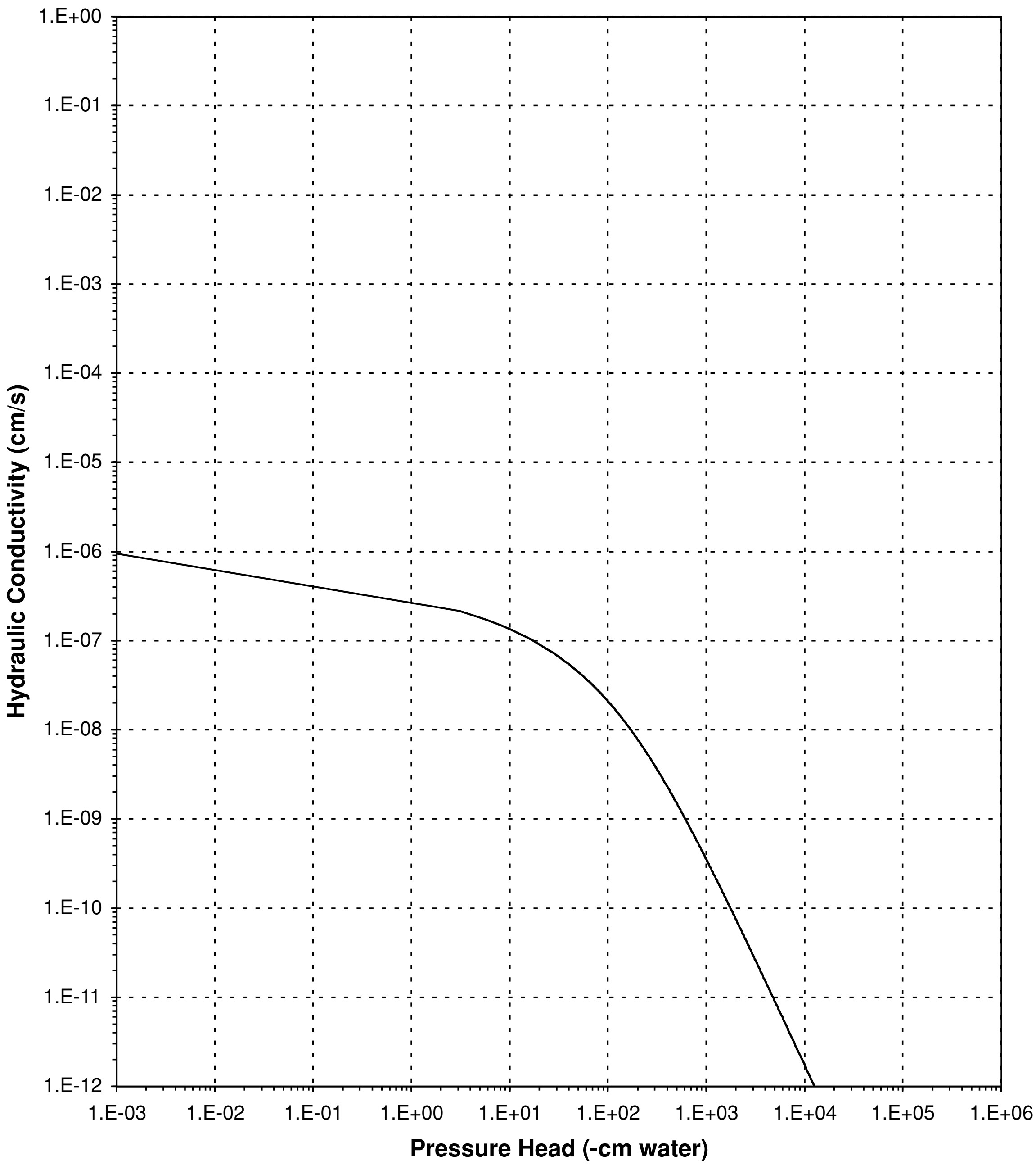
Plot of Hydraulic Conductivity vs Pressure Head

Sample Number: 8805



Appendix E

Westbay's MP55 Well Components Installed in R-12

Summary Casing Log

Company: LANL
Well: R12
Site:
Project: Hydrogeology Characterization

Job No: WB777
Author: DL

Well Information

Reference Datum: ground level
Elevation of Datum: msl
MP Casing Top: 0.00 ft.
MP Casing Length: 853.10 ft.
Well Description:
Plastic MP55 System
Other References:
4.5 in ID SS casing+screens: LANL1/11/00
Mild Steel 4.3ID, Backfill: LANL 1/26/00
MagneticCollars 2.5 ft below port top

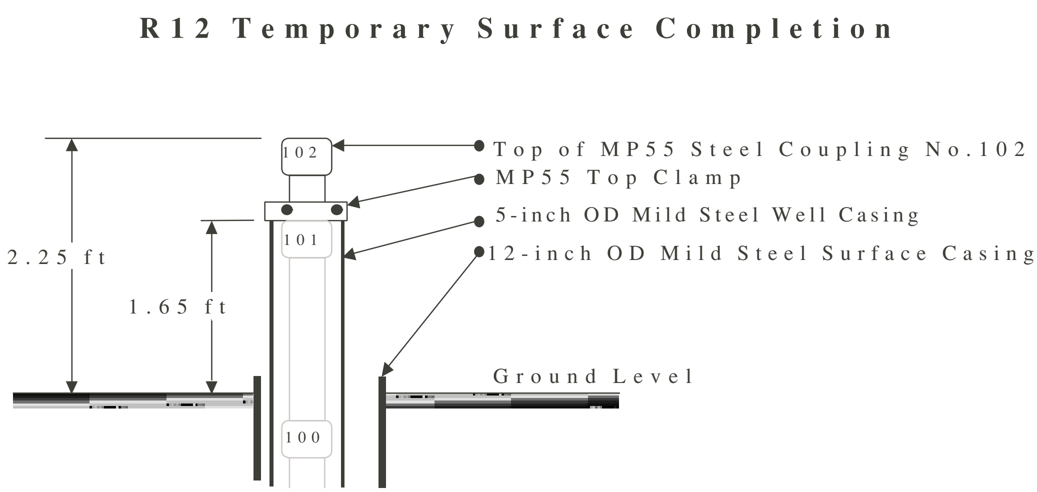
Borehole Depth: 870.00 ft.
Borehole Inclination: vertical
Borehole Diameter: 12.00 in.

File Information

File Name: 777_R12.WWD
Report Date: Tue Aug 08 12:16:56 2000

File Date: Apr 07 21:48:24 2000

Sketch of Wellhead Completion

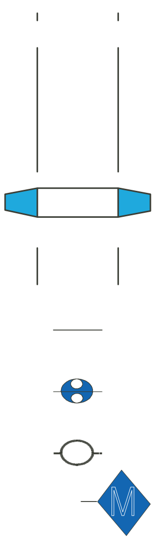


Summary MP Casing Log
LANL

Job No: WB777
Well: R12

Legend

(Qty) MP Components



(2) 0603 - MP55 End Plug

(8) 0601M10 - MP55 Casing, PVC, 1.0m

(74) 0601M30 - MP55 Casing, PVC, 3.0m

(7) 0611M15 - MP55 Packer, no stiffeners

(13) 0601M15 - MP55 Casing, PVC, 1.5m

(89) 0602 - MP55 Regular Coupling

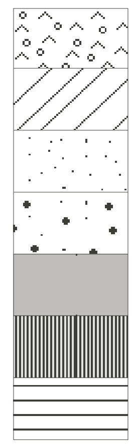
(11) 0605 - MP55 Measurement Port

(4) 0607 - MP55 Hydraulic Pumping Port

(5) 0608 - MP55 Magnetic Location Collar

Geology

Backfill/Casing



Concrete

Bentonite

Sand Fine

Sand Coarse

Mild Steel

Stainless Steel

Well Screen

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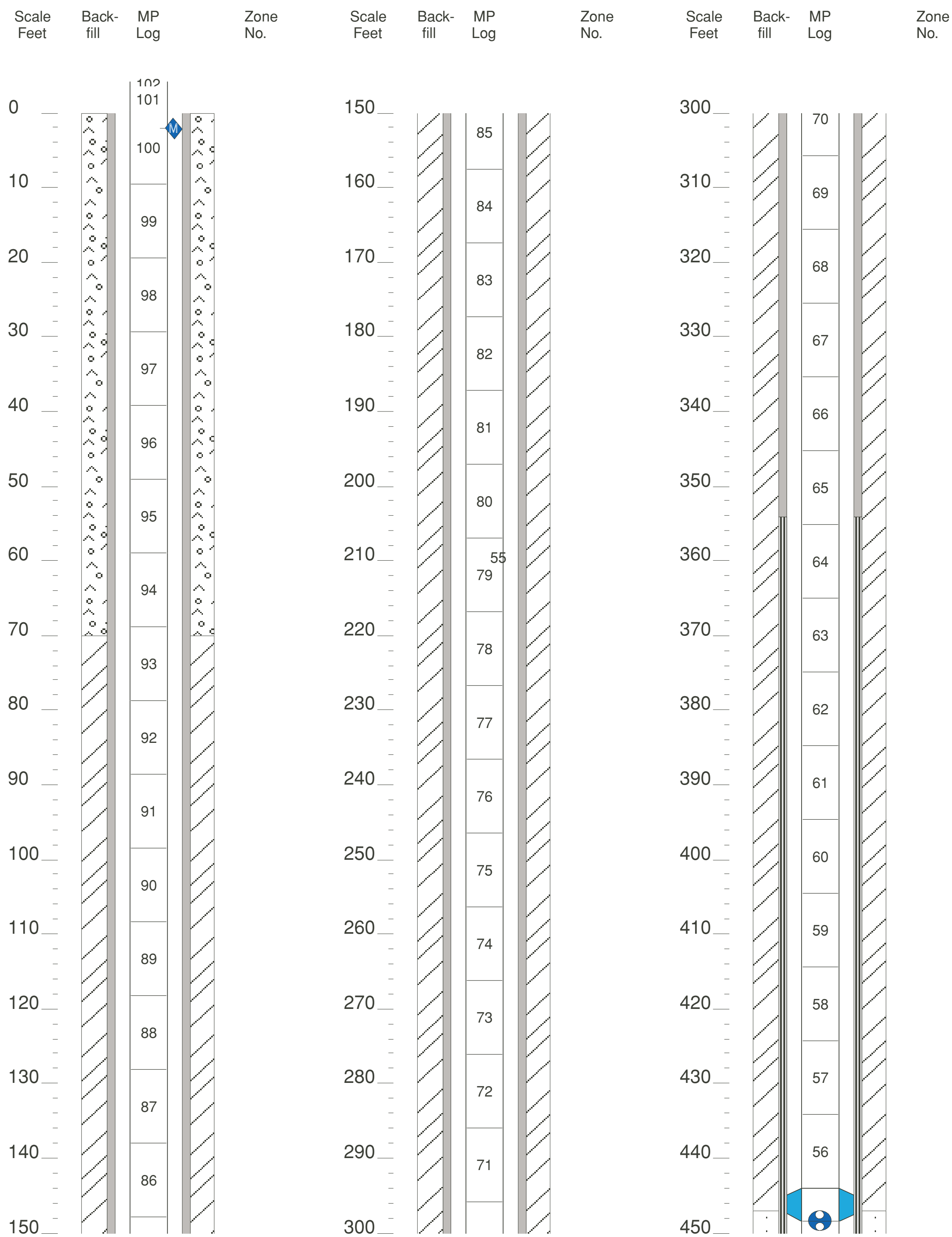
Summary MP Casing Log
LANL

Job No: WB777
Well: R12



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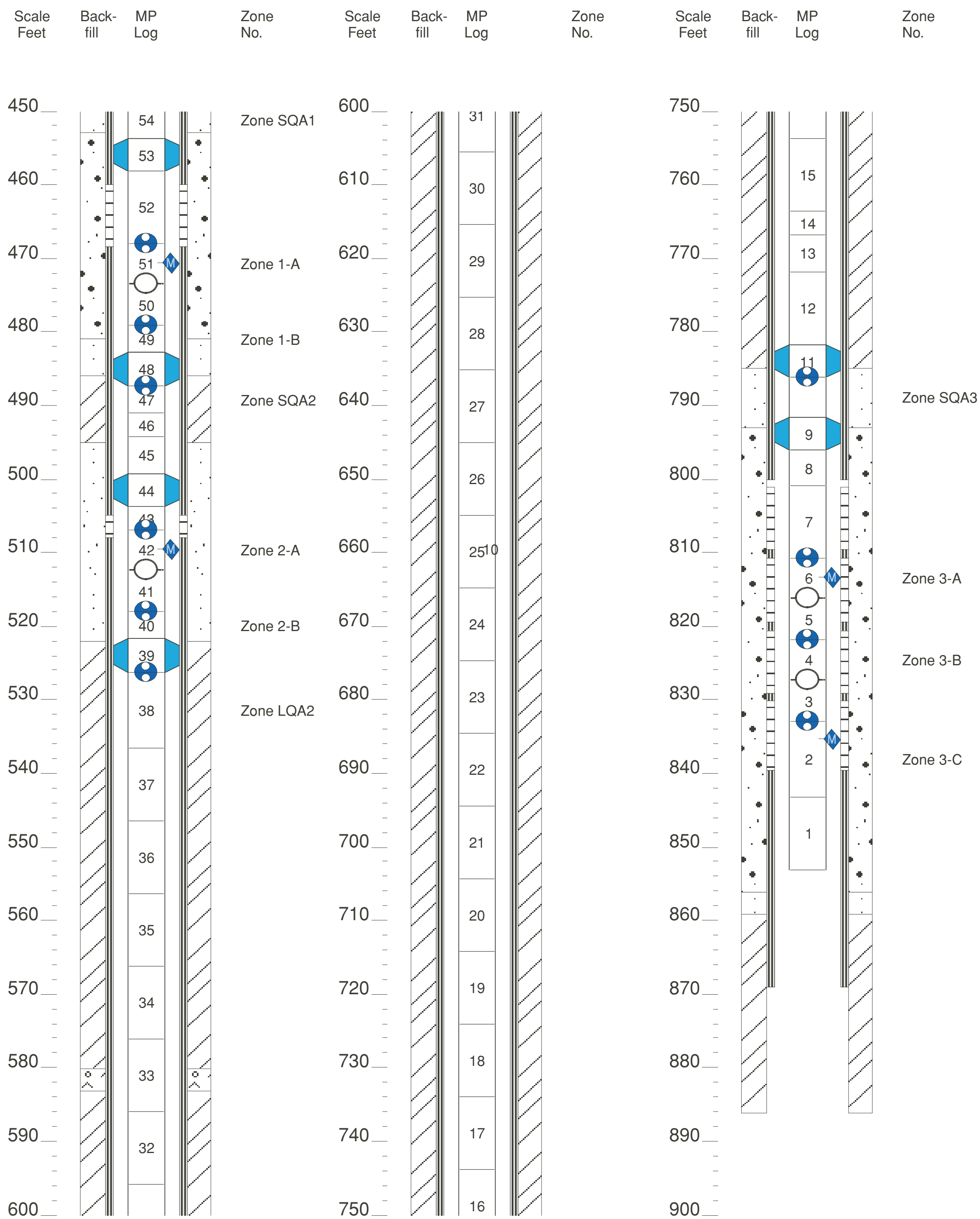
Summary MP Casing Log
LANL

Job No: WB777
Well: R12



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